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Application for Patent

C:31323

אני, (שם המבקש, מענו -- ולגבי גוף מאוגד -- מקום התאגדותו)
I (Name and address of applicant, and, in case of body corporate-place of incorporation)

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(באנגלית) (English) APPARATUS AND METHOD FOR FABRICATING FLAT WORKPIECES

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*בקשת חלוקה - Application for Division	*בקשת פטנט מוסף - Application for Patent of Addition	*דרישה דין קדימה Priority Claim		
מבקשת פטנט from Application	*לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No. ____ .מס dated ____ מיום	No. ____ .מס dated ____ מיום			

*יפוי כח: כללי/מיוחד - רצוף בזה / עוד יוגש
P.O.A.: general / individual - attached / to be filed later -
filed in case ____ הוגש בענין

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היום 2 בחודש November שנת 1998
This 2 of November of the year 1998

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APPARATUS AND METHOD FOR FABRICATING FLAT WORKPIECES

ORBOTECH LTD.
C: 31323

אורבוטק בע"מ

APPARATUS AND METHOD FOR FABRICATING FLAT WORKPIECES

Field of Invention

The present invention relates to the fabrication and inspection of flat workpieces in general and more particularly to the fabrication and inspection of flat panel display screens (FPDs) for computers, television and similar applications.

Background of the Invention

Flat panel visual displays such as liquid crystal displays (LCDs) are becoming increasingly popular for use in computer and television screens. However their cost remains high, in part, due to relatively low manufacturing yields.

There exist various well known techniques for FPD fabrication. Most of these techniques comprise a multi-step photolithographic process in which various thin films and photo-sensitive protective photoresist coatings are applied in turn to a glass substrate. The thin films may be metallic, non-metallic dielectric or the like depending on the particular process step. The photoresist coatings are selectively exposed, typically to UV light, developed and selectively washed away from the substrate. The thin films are etched to selectively remove parts not protected by residual photoresist. Repetition of this process deposits on the substrate a multi-layered matrix structure of metal connectors, thin film transistors, filters and individually controllable liquid crystal cells.

Various steps in the FPD fabrication process are highly sensitive to airborne and other impurities as well as to process defects. Unfiltered air typically contains many millions of airborne particles, such as dust, per cubic meter. Conventional FPD fabrication techniques require that the maximum level of airborne particulate concentration range between 10 - 100 particles per cubic meter, depending of the sensitivity of the given process step. Consequently,

FPDs are typically fabricated in environments containing highly filtered air which provide reduced contamination by airborne particles.

FPD fabrication facilities are typically situated in so-called "clean rooms" in which the ambient air is filtered to maintain a level of airborne particulate contamination which is at the upper end of the above-mentioned concentration range, typically at a concentration level of less than 100 airborne particles per cubic meter. This level of particulate contamination is insufficiently low for some fabrication steps. However, it is generally impracticable, because of cost and limitations on human access, to maintain large volumes of air in a clean room at the low levels of airborne particulate concentration required for such extremely contamination-sensitive fabrication steps. Consequently, FPD fabrication equipment performing steps requiring an even lower level of airborne particulate concentration typically includes a self-contained ultra clean micro-environment in which the required low concentration of airborne particulate concentration is maintained.

In a typical FPD fabrication facility, human attendants are permitted into the clean room facilities having maximum concentration levels as low as 100 particles per cubic meter, however the attendants must be suitably dressed in protective clothing. Human attendants, even in suitable dress, typically are not permitted into the self-contained micro environments of equipment in which maximum concentration levels of airborne contamination is maintained at below 100 particles per cubic meter. Consequently, equipment operating in its own ultra clean self-contained micro environment at maximum concentration of airborne particles less than 100 particles per cubic meter is typically fully automated and is operational without human intervention from inside the machine.

It is well known to inspect FPD substrates during and following fabrication. Conventional automated inspection techniques are directed to ascertaining the uniformity of a matrix structure deposited on a glass substrate, determining whether dust has been trapped in

intermediate matrix layers on the FPD, and ascertaining the performance of completed FPD panels. In addition non-automated human inspection is used to determine the existence of large scale process defects such as chemical residues that have not been fully washed away, streaks, scratches and uneven exposure of the photoresist. The present invention relates to inspections of this latter type.

Conventionally, all inspection of FPD substrates is performed in a clean room but outside the self-contained ultra-clean micro environments of the FPD fabrication equipment. A batch of substrates is typically inspected only after a series of process steps is completed. There is often a considerable time delay between the completion of a fabrication process and inspection. In the event of recurring contamination or recurring process flaws, many substrates may be affected before the substrates are inspected.

A conventional automated system for inspecting FPD substrates during fabrication for ascertaining the uniformity of the matrix structure deposited on the glass substrate and determining whether dust has been trapped in intermediate matrix layers thereof, is commercially available from the present assignee, Orbotech Ltd. of Israel, Cat. No. LC 3090. Part of this system is described and claimed in U.S. Patent 5,333,052.

The existing Orbotech system described above is not normally used for identifying many typical fabrication large scale process defects on FPD substrates because it collects data relating to a matrix structure having dimensions that are orders of magnitude smaller than those of typical process defects. Moreover, because the system scans the substrates, it is physically relatively large, expensive and complex to operate.

Human inspection for process defects is conventionally performed by an operator situated inside the clean room who positions a substrate under a light source to inspect it for undesired residues, streaks, scratches and other relatively large scale anomalies on the substrate. While such inspection can be useful to detect certain large scale fabrication process defects, it

takes place outside the self- contained ultra-clean micro environment of contamination-sensitive process equipment and it suffers from the typical high cost and non-standardization associated with non-automated human inspection methods.

Other types of inspection, typified by the disclosure of US Patent 5,771,068, assigned to the present assignee and incorporated herein by reference, are conventionally used to inspect FPDs that are sufficiently completed to enable selective activation of pixels. According to an embodiment described in US Patent 5,771,068, various combinations of pixels are illuminated and a relatively low resolution staring array sensor images the entire substrate as the various combinations are illuminated. The images are analyzed for variations in intensities. This type of inspection is clearly not suitable for inspection FPD substrates in intermediate stages of fabrication.

Summary of Invention

It is an object of the present invention to overcome the drawbacks of conventional FPD inspection systems and provide an improved system and method for automated inspection of FPDs.

It is a further object of the present invention to provide an FPD manufacturing system having increased yield.

It is still a further object of the present invention to provide an automated system for inspecting FPDs which is less expensive and more compact in size than conventional automated scanning FPD inspection systems.

It is an additional object of the present invention to inspect FPD substrates inside the self-contained ultra-clean micro environment of equipment performing contamination-sensitive FPD fabrication processes.

In accordance with a preferred embodiment of the invention, a system and method are provided for the manufacture of FPDs using contamination-sensitive fabrication process equipment having a self-contained ultra clean micro environment characterized by an airborne particulate concentration that is substantially lower than that of its surroundings, wherein automated inspection apparatus is provided inside the self-contained ultra clean micro environment of the process equipment. Accordingly, FPD substrates are inspected inside the self-contained ultra clean environment before transportation to other process equipment to perform a down stream fabrication process.

In a preferred embodiment of the invention, the inspection of FPD substrates is performed inside process equipment immediately following the completion of a series of fabrication process steps and before the substrate is transferred to other equipment to perform the next series of steps. A determination is made of whether there exist any process defects on

the substrate in order that the operation of the process equipment that is performing defective steps can be interrupted and corrected before a recurring defect affects subsequent substrates.

According to a preferred embodiment of the invention, a system and method for FPD fabrication are provided in which FPD substrates are inspected for typical fabrication process defects by an automated system, without reference to the underlying matrix structure on the FPD substrate.

In a preferred embodiment, inspection is provided to detect typical fabrication process defects including scratches, process residues, uneven exposure of photoresist, uneven deposition of films and particulate contamination.

In some other preferred embodiments of the invention, a system is provided to inspect coatings applied to the substantially flat surfaces of industrial objects.

There is also provided in accordance with a preferred embodiment of the present invention a system for manufacture of flat panel displays including a plurality of manufacturing devices located in a first controlled airborne particle contamination environment, at least some of the plurality of manufacturing devices each including an enclosure defining a second controlled airborne particle contamination environment having a lower level of contamination than that of the first controlled airborne particle contamination environment, and a plurality of optical inspection devices operative to inspect flat panel display substrates at various stages of the production thereof by the plurality of manufacturing devices, at least some of the plurality of optical inspection devices being located within the enclosures defining the second controlled airborne particle contamination environments.

Further in accordance with a preferred embodiment of the present invention the plurality of optical inspection devices are operative in coordination with the plurality of manufacturing devices for inspecting the substrates prior to transfer thereof out of the second controlled airborne particle contamination environment.

Still further in accordance with a preferred embodiment of the present invention the at least some of the plurality of optical inspection devices include non-scanning sensors.

Additionally in accordance with a preferred embodiment of the present invention the plurality of optical inspection devices are operative to identify fabrication process defects occurring during production of flat panel display substrates.

Moreover in accordance with a preferred embodiment of the present invention the process defects include at least one of the following: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

Further in accordance with a preferred embodiment of the present invention the each of the plurality of optical inspection devices includes at least one non-scanning sensor which views substantially all of the surface of the substrate.

Still further in accordance with a preferred embodiment of the present invention the at least one non-scanning sensor includes a plurality of non-scanning sensors the each sensor views a portion of the substrate and together the plurality of sensors views substantially the entire surface of the substrate.

Additionally in accordance with a preferred embodiment of the present invention the each of the plurality of optical inspection devices includes an illuminating array operative to provide various combinations of illumination.

Moreover in accordance with a preferred embodiment of the present invention the combinations include at least dark field and substantially bright field illumination.

Further in accordance with a preferred embodiment of the present invention the non-scanning sensor acquires at least one image of the substrate for each combination.

Still further in accordance with a preferred embodiment of the present invention the system also includes an image analyzer for identifying process defects by computer analysis

of a plurality of image of the substrate taken with various ones of the combinations of illumination.

Additionally in accordance with a preferred embodiment of the present invention the image analyzer is operative without comparison to an external reference.

Moreover in accordance with a preferred embodiment of the present invention the enclosure contains a first plurality of illuminators mounted on a first wall of the enclosure and a second plurality of illuminators mounted on a second wall of the enclosure, orthogonal to the first wall.

Further in accordance with a preferred embodiment of the present invention the system also includes directionally adjustable illuminators..

Still further in accordance with another preferred embodiment of the present invention there is provided an inspection system for use in inspecting flat panel displays including a non-scanning optical array for viewing a flat panel display substrate, and an illumination subsystem sequentially providing dark field and bright field illumination of the flat panel display substrate when the optical array views the flat panel display substrate.

Additionally the illumination subsystem provides various combinations of dark field and bright field illumination of the flat panel display substrate when the optical array views the flat panel display substrate.

Further in accordance with a preferred embodiment of the present invention, the system includes a spatially positionable stage to support the flat panel display substrate, and the stage spatially positions the substrate at various angles relative to the illumination subsystem.

Moreover in accordance with a preferred embodiment of the present invention the system also includes an image analyzer receiving an output from the non-scanning optical array and being operative to detect process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of

a photo-resist deposited on the substrate, scratches, lines, particles.

Further in accordance with a preferred embodiment of the present invention the optical array views substantially all of a surface of the substrate.

Still further in accordance with a preferred embodiment of the present invention the optical array acquires at least one image of the substrate for each of a plurality of different illuminations.

Additionally in accordance with a preferred embodiment of the present invention the image analyzer identifies the defects by computer analysis of a plurality of images of the substrate taken at differing illumination.

Moreover in accordance with a preferred embodiment of the present invention the system also includes an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

Further in accordance with a preferred embodiment of the present invention the system also includes a third illuminator mounted on a third wall of the enclosure.

Still further in accordance with a preferred embodiment of the present invention the system also includes a diffuser associated with the illumination subsystem.

Additionally in accordance with a preferred embodiment of the present invention the system includes an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of the optical array, the illumination subsystem and the substrate.

There is also provided in accordance with a preferred embodiment of the present invention an inspection system for use in inspecting objects including a non-scanning optical array for viewing an object, and an illumination subsystem sequentially providing dark field and bright field illumination of the flat panel display substrate when the optical array views the object.

Further in accordance with a preferred embodiment of the present invention the illumination subsystem provides various combinations of dark field and bright field illumination of the object when the optical array views the object.

Still further in accordance with a preferred embodiment of the present invention the system also includes an image analyzer receiving an output from the non-scanning optical array and being operative to detect process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

Additionally in accordance with a preferred embodiment of the present invention the optical array views substantially all of a surface of the substrate.

Moreover in accordance with a preferred embodiment of the present invention the optical array acquires at least one image of the substrate for each of a plurality of different illuminations.

Further in accordance with a preferred embodiment of the present invention the image analyzer identifies the defects by computer analysis of a plurality of images of the substrate taken at differing illumination.

Still further in accordance with a preferred embodiment of the present invention the system also includes an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

Additionally in accordance with a preferred embodiment of the present invention the system also includes a third illuminator mounted on a third wall of the enclosure.

Moreover in accordance with a preferred embodiment of the present invention the system also includes a diffuser associated with the illumination subsystem.

Further in accordance with a preferred embodiment of the present invention the system includes an adjustable mounting assembly for selectably determining at least one of

relative inclination, spatial separation and axial orientation of at least two of the optical array, the illumination subsystem and the substrate.

There is also provided in accordance with a preferred embodiment of the present invention apparatus for optically inspecting the surface of an article having a substantially planar surface, including an inspection region, illumination apparatus to selectably illuminate the surface of an article located in the inspection region with at least two predetermined configurations of illumination, an image acquisition sub-system including at least one non-scanning camera for acquiring images of the surface of the article when illuminated by at least one predetermined configuration of illumination, and an image analysis subsystem for computer analyzing the images and detecting anomalies in the surface as a function of variations in reflected intensities of illumination.

There is additionally provided a spatially positionable stage for supporting the article in the inspection region in selectable orientation relative to the illumination apparatus.

Moreover, in accordance with a preferred embodiment of the invention the image analysis subsystem is operative to identify anomalies that are substantially the same size as the resolution of the camera.

There is additionally provided in accordance with a preferred embodiment of the present invention apparatus for coating an article having a substantially planar surface, including a coating generator operative to generate a coating on a surface of the article, an illuminator for selectably illuminating the surface bearing the coating with at least two predetermined configurations of illumination, an image acquisition sub-system including at least one non-scanning sensor for acquiring images of the surface of the article for each combination of illumination, and an image analysis subsystem for analyzing the images and detecting anomalies in the surface on the basis of variations in reflected intensities of illumination.

There is also provided in accordance with a preferred embodiment of the present

invention apparatus for inspecting an article in a clean room, including an inspection device situated in the clean room and including an inspection stage selectably positionable by remote control, at least one non-scanning sensor viewing the substantially the entire inspection stage, an array of illuminators illuminating the inspection stage, automated feed apparatus for placing articles in the inspection device, a remote control situated outside the clean room for viewing articles placed in the inspection device, the remote control including a viewer and a controller for remotely positioning the stage and selecting combinations of illumination.

There is also provided in accordance with a preferred embodiment of the present invention a method for manufacture of flat panel displays including providing a plurality of manufacturing devices located in a first controlled airborne particle contamination environment, at least some of the plurality of manufacturing devices each including an enclosure defining a second controlled airborne particle contamination environment having a lower level of contamination than that of the first controlled airborne particle contamination environment, and inspecting flat panel display substrates at various stages of the production thereof by the plurality of manufacturing devices at a location within the enclosures defining the second controlled airborne particle contamination environments.

Further in accordance with a preferred embodiment of the present invention the inspecting step includes inspecting the substrates prior to transfer thereof out of the second controlled airborne particle contamination environment.

Still further in accordance with a preferred embodiment of the present invention the inspecting step includes inspecting using non-scanning sensors.

Additionally in accordance with a preferred embodiment of the present invention the method further includes identifying fabrication process defects occurring during production of flat panel display substrates.

Moreover in accordance with a preferred embodiment of the present invention the

identifying step includes identifying process defects including at least one of the following: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

Further in accordance with a preferred embodiment of the present invention the inspecting step includes inspecting using at least one non-scanning sensor which views substantially all of the surface of the substrate.

Still further in accordance with a preferred embodiment of the present invention the inspecting step includes inspecting using a plurality of non-scanning sensors the each sensor views a portion of the substrate and together the plurality of sensors views substantially the entire surface of the substrate.

Additionally in accordance with a preferred embodiment of the present invention the inspecting step includes illuminating the substrate with an illuminating array operative to provide various combinations of illumination.

Moreover in accordance with a preferred embodiment of the present invention the combinations include at least dark field and substantially bright field illumination.

Further in accordance with a preferred embodiment of the present invention the inspecting step includes acquiring at least one image of the substrate for each combination using the non-scanning sensor.

Still further in accordance with a preferred embodiment of the present invention the method also includes image-analyzing the process defects by computer analysis of a plurality of image of the substrate taken with various ones of the combinations of illumination.

Additionally in accordance with a preferred embodiment of the present invention the image-analyzing step is performed without comparison to an external reference.

Moreover in accordance with a preferred embodiment of the present invention the providing step includes further providing the enclosure with a first plurality of illuminators

mounted on a first wall of the enclosure and a second plurality of illuminators mounted on a second wall of the enclosure, orthogonal to the first wall.

Further in accordance with a preferred embodiment of the present invention the providing step includes further providing directionally adjustable illuminators.

There is also provided in accordance with a preferred embodiment of the present invention an method for inspecting flat panel displays including viewing a flat panel display substrate using a non-scanning optical array, and sequentially illuminating the flat panel display substrate with dark field and bright field illumination when the optical array views the flat panel display substrate.

Further in accordance with a preferred embodiment of the present invention the sequentially illuminating step illuminates using various combinations of dark field and bright field illumination of the flat panel display substrate when the optical array views the flat panel display substrate.

Still further in accordance with a preferred embodiment of the present invention the method also includes receiving an output from the non-scanning optical array, and detecting process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

Additionally in accordance with a preferred embodiment of the present invention the viewing step includes viewing substantially all of a surface of said substrate.

Moreover in accordance with a preferred embodiment of the present invention the viewing step includes acquiring at least one image of the substrate for each of a plurality of different illuminations.

Further in accordance with a preferred embodiment of the present invention the detecting step includes identifying the defects by computer analysis of a plurality of images of

the substrate taken at differing illumination.

Still further in accordance with a preferred embodiment of the present invention the method also includes providing an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

Additionally in accordance with a preferred embodiment of the present invention the providing step also includes providing a third illuminator mounted on a third wall of the enclosure.

Moreover in accordance with a preferred embodiment of the present invention the method also includes providing a diffuser associated with the illumination subsystem.

Further in accordance with a preferred embodiment of the present invention the method also includes providing an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of the optical array, the illumination subsystem and the substrate.

There is also provided in accordance with a preferred embodiment of the present invention an method for inspecting objects including viewing an object using a non-scanning optical array, and sequentially illuminating the object with dark field and bright field illumination when the optical array views the object.

Further in accordance with a preferred embodiment of the present invention the sequentially illuminating step illuminates using various combinations of dark field and bright field illumination of the object when the optical array views the object.

Still further in accordance with a preferred embodiment of the present invention the method also includes receiving an output from the non-scanning optical array, and detecting process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on

the substrate, scratches, lines, particles.

Additionally in accordance with a preferred embodiment of the present invention the viewing step includes viewing substantially all of a surface of the object.

Moreover in accordance with a preferred embodiment of the present invention the viewing step includes acquiring at least one image of the object for each of a plurality of different illuminations.

Further in accordance with a preferred embodiment of the present invention the detecting step includes identifying the defects by computer analysis of a plurality of images of the object taken at differing illumination.

Still further in accordance with a preferred embodiment of the present invention the method also includes providing an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

Additionally in accordance with a preferred embodiment of the present invention the providing step also includes providing a third illuminator mounted on a third wall of the enclosure.

Moreover in accordance with a preferred embodiment of the present invention the method also includes providing a diffuser associated with the illumination subsystem.

Further in accordance with a preferred embodiment of the present invention the method also includes providing an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of the optical array, the illumination subsystem and the object.

There is also provided in accordance with a preferred embodiment of the present invention a method for optically inspecting the surface of an article having a substantially planar surface, including defining an inspection region, selectably illuminating the surface of an article

located in the inspection region with at least two predetermined configurations of illumination, acquiring images of the surface of the article when illuminated by at least one predetermined configuration of illumination using at least one non-scanning camera, and analyzing the images and detecting anomalies in the surface as a function of variations in reflected intensities of illumination.

There is additionally provided in accordance with a preferred embodiment of the present invention a method for coating an article having a substantially planar surface, including generating a coating on a surface of the article, selectably illuminating the surface bearing the coating with at least two predetermined configurations of illumination, acquiring images of the surface of the article for each combination of illumination using at least one non-scanning sensor, and analyzing the images and detecting anomalies in the surface on the basis of variations in reflected intensities of illumination.

There is also provided in accordance with a preferred embodiment of the present invention a method for inspecting an article in a clean room, including situating an inspection device in the clean room, selectably positioning an inspection stage of the inspection device by remote control, viewing substantially the entire inspection stage using at least one non-scanning sensor of the inspection device, illuminating the inspection stage using an array of illuminators of the inspection device, placing articles in the inspection device using automated feed apparatus of the inspection device, and situating a remote controller outside the clean room for viewing articles placed in the inspection device, the remote controller including a viewer and a controller for remotely positioning the stage and selecting combinations of illumination.

There is additionally provided in accordance with a preferred embodiment of the present invention a method for inspecting the surface of an article, including the steps of placing the article in an inspection region defined by a stage, illuminating a portion of the surface of the article with at least one configuration of dark field illumination, acquiring an image of

substantially the entire surface for the at least one configuration of dark field illumination, illuminating the surface with at least one configuration of substantially bright field illumination, acquiring an image of substantially the entire surface for the at least one configuration of substantially bright field illumination, computer analyzing the images to determine non uniformities in reflected intensities.

Further in accordance with a preferred embodiment of the present invention the at least one configuration of dark field illumination includes a plurality of dark field illumination combinations, and separate images are acquired for each of the combinations.

Still further in accordance with a preferred embodiment of the present invention the at least one configuration of substantially bright illumination includes a plurality of bright field illumination combinations, and separate images are acquired for each of the combinations.

Additionally in accordance with a preferred embodiment of the present invention the additional step for each predetermined combination of illumination of selecting a predetermined inclination and orientation of the substrate, and acquiring separate images of the surface for each the inclination and axial orientation.

Moreover in accordance with a preferred embodiment of the present invention the additional step of optically treating the illumination prior to acquiring an image.

Further in accordance with a preferred embodiment of the present invention the treatment is provided by optical filters.

Still further in accordance with a preferred embodiment of the present invention the filters filter for selected wavelengths.

Additionally in accordance with a preferred embodiment of the present invention the filters filter for selected polarization.

Moreover in accordance with a preferred embodiment of the present invention the surface is illuminated with a selected combination of broad spectrum illumination and imaged

with filtered illumination in a first predetermined spectral range, and subsequently imaged with filtered illumination in a second predetermined spectral range.

Further in accordance with a preferred embodiment of the present invention the surface is illuminated with a first combination of filtered illumination in a predetermined spectral range and imaged, and subsequently illuminated with a second combination of illumination in a predetermined spectral range and imaged.

Still further in accordance with a preferred embodiment of the present invention the surface is illuminated with a selected combination of broad spectrum illumination and imaged with filtered illumination in a first predetermined polarization, and subsequently imaged with filtered illumination in a second predetermined polarization.

Additionally in accordance with a preferred embodiment of the present invention the surface is illuminated with a first combination of filtered illumination in a predetermined polarization and imaged, and subsequently illuminated with a second combination of illumination in a predetermined polarization and imaged.

Moreover in accordance with a preferred embodiment of the present invention the additional step of blurring the image during acquisition.

Further in accordance with a preferred embodiment of the present invention the at least one image is blurred by introducing relative movement between at least two of the following: the surface, the camera, and an optical element between the surface and the camera.

Still further in accordance with a preferred embodiment of the present invention the further step of computer analyzing the non-uniformities to determine the presence of defects in coatings on the substrate.

Additionally in accordance with a preferred embodiment of the present invention the article is a flat display panel substrate.

There is also provided in accordance with a preferred embodiment of the present

invention a method for coating the surface of an article with a film, including the steps of depositing a film coating on at least part of a surface of the article, placing the article in an inspection region, illuminating a portion of the coated surface of the article with at least one configuration of dark field illumination, acquiring an image of the surface illuminated by the at least one configuration of dark field illumination, illuminating the surface with at least one configuration of substantially bright field illumination, acquiring an image of the entire surface illuminate by the least one configuration of substantially bright field illumination, computer analyzing each image to determine non uniformities in reflected intensities.

Brief Description of the Drawings

The present invention will be appreciated, by way of example only, with reference to the following detailed description in conjunction with the accompanying drawings in which:

Fig. 1 is a pictorial illustration of a clean room for FPD fabrication having located therein a system for inspecting FPD substrates constructed and operative according to a preferred embodiment of the present invention;

Fig. 2A - 2E are illustrations of a typical FPD substrate and various typical fabrication process flaws which may occur during fabrication thereof;

Fig. 3 is an illustration of an inspection system constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 4 is an illustration of an illumination unit useful in a preferred embodiment of the invention;

Fig. 5 is an illustration an inspection stage which is movable about multiple axes in accordance with a preferred embodiment of the invention;

Fig. 6 is an illustration of the geometry of bright field illumination employed in a preferred embodiment of the invention;

Fig. 7 is an illustration of the geometry of one type of dark field illumination employed in a preferred embodiment of the invention;

Fig. 8 is an illustration of the geometry of another form of dark field illumination employed in a preferred embodiment of the invention;

Fig. 9 is an illustration of the structure and operation of an optical head of a preferred embodiment of the invention;

Fig. 10 is a simplified flow chart illustrating operation of a system for generating a patterned coating on a surface of a planar substrate and inspecting the surface in accordance with

a preferred embodiment of the invention;

Fig. 11 is an illustration of various alternative structures for illumination and image acquisition which may be incorporated in an inspection system constructed and operative in accordance with additional preferred embodiments of the present invention; and

Fig. 12 is an illustration of an additional preferred embodiment of an inspection system in accordance with the present invention.

Detailed Description of Preferred Embodiments

Reference is made to Fig. 1, which illustrates part of an FPD fabrication facility 10 comprising a number of units of fabrication process equipment 12, at least some of which include an inspection system 14 in accordance with the present invention.

FPD fabrication is extremely sensitive to contamination by airborne particles. FPD fabrication is therefore conducted in so-called "clean areas", having a controlled environment of highly filtered air. Different processes require different tolerances of air purity. A typical clean area used for FPD fabrication may have a concentration of airborne particulate impurities, such as dust, of between 10 - 100 particles per cubic meter of air. In order to maintain such low concentrations of airborne particles, FPD fabrication operations are preferably highly mechanized.

Fabrication equipment 12 is generally highly automated and self-contained. Each unit of equipment 12 is situated in a clean room 13 and performs a predetermined series of fabrication process steps. Automated trolleys 16 running on pathways 18 in the clean room 13 are used to transport cassettes 20 of in-fabrication FPD substrates to and from the automated fabrication equipment during the fabrication process. To minimize contamination, only a few human attendants 22 are permitted into the clean room 13. Moreover, attendants 22 in the clean room 13 are required to wear specially designed attire to further reduce contamination.

FPD structures and fabrication processes are well known and are described in detail, for example in Castellano, J. et. Al., "Liquid Crystal Displays", Stanford Resources, Inc., 1995. The particulars of any given fabrication process are not part of this invention. A generalized description of FPD structure and fabrication, is now provided by way of example only in order that the description of the present invention may be more readily understood.

A typical FPD substrate, shown in Fig. 2A, comprises a glass substrate 24 having a

multi-layered matrix structure, typically comprising individually controllable liquid crystal cells 25, uniformly deposited thereon. The size of the cells is typically be in the order of 90 X 270 microns. The cells are interconnected by connectors having a typical line width of the order of 7 microns. A typical substrate measures between 405 X 505mm and 650 X 830mm and contains a plurality of multi-layered matrices 26, of which four are shown.

The matrix structure is preferably obtained by a repetitive multi-step process generally including the deposition of a metallic or non-metallic thin film on the substrate 24; coating the film with a radiation sensitive photoresist; exposing the photoresist to radiation according to a predetermined pattern; developing the photoresist and selectively washing away those parts of the photoresist that are exposed (or in some processes not exposed); etching away those parts of the thin film not protected by residual photoresist, to thereby form the predetermined pattern in the thin film; and stripping away residual photoresist that overlays the resulting pattern. Each of these steps may be performed by various alternative techniques, the particulars of which are not of importance for the current invention. As the result of multiple repetitions of the foregoing steps, multi-layered matrices 26 are generated.

Typically each unit of fabrication equipment 12 handles a number of associated steps in the fabrication process. For example, some fabrication equipment deposits thin metallic film layers on the glass substrate 24. Other fabrication equipment coats the resulting metallic film with photoresist, exposes the photoresist according to a pattern, develops the photoresist and selectively removes exposed or unexposed photoresist. Still other fabrication equipment etches the metallic layer to remove those parts of the metal film that are not protected by residual photoresist. Still other fabrication equipment strips residual photoresist overlying the resultant pattern.

A typical clean room comprises an area of hundreds of square meters. Because human attendants cannot be excluded from such clean rooms and because of the extremely high cost of

maintaining clean rooms at the lower end of the permitted range of contamination, the large clean rooms typically have concentration level of airborne particles per cubic meter that is maintained at the upper end of the permitted range, approximately 100 airborne particles per cubic meter.

In order to meet the demands of low airborne particulate concentration required by some of the fabrication steps within the clean room 13, various critical fabrication equipment 12 is provided with enclosure defining a second controlled self-contained airborne particle contamination environment. This second self-contained environment is preferably maintained at a lower level of airborne contamination relative to the clean room. For typical fabrication equipment, the self-contained environment is maintained preferably at about 10 airborne particles per cubic meter.

Inside the second self-contained controlled environment, in-fabrication FPD substrates are typically handled by robots (not shown). FPDs are typically fabricated in batches, with each batch being carried in cassettes 20 between various second self-contained environments situated at different locations in the clean room.

Processes that are performed in fabrication equipment 12 are potentially subject to process flaws. Referring now to Figs. 2B - 2E, illustrative examples of typical detectable large scale process flaws are shown. Typical fabrication process flaws include: deposits of chemical residues 28 that remain on the substrate because of incomplete washing; areas 30 of incomplete or missing matrix resulting from uneven exposure of photoresist, and subsequent uneven or incomplete deposition of matrix 26 in those areas; rinse tracks 32 that remain on the substrate after washing between processes; scratches 34; lines 36 and embedded particles 38. Additional fabrication process defects include various other anomalies such as uneven deposition of films and coatings on the substrate (not shown). It is to be appreciated that this list of fabrication process flaws may be considered representative of typical defects, and is by no means limiting.

Process flaws such as those described above may affect individual FPD substrates, or an entire batch of FPD substrates being processed by a particular unit of fabrication equipment. For example, a robot loader that handles FPD substrates inside fabrication equipment 12 may scratch all the substrates that it handles, thus rendering the substrates defective, or the timing of a rinse may be improperly set so that chemical residues are not fully washed of substrate.

In order to identify defective in-fabrication FPD substrates as early as possible in the fabrication process, in accordance with a preferred embodiment of the present invention optical inspection apparatus 14 is situated inside the controlled self-contained environment of fabrication equipment 12 to automatically inspect substrates 24 after the completion of a fabrication process but before removal to fabrication equipment performing downstream fabrication processes. In accordance with an addition feature of the present invention, optical inspection apparatus 14 constructed and operative in accordance with the present invention may be configured as stand-alone equipment situated in the clean room, but outside of equipment 12.

A perspective view of inspection apparatus 14, constructed and operative in accordance with a preferred embodiment of the invention and operative to identify defective FPD substrates, appears in Fig. 3. Inspection apparatus 14 preferably comprises an upper substantially fully enclosed inspection enclosure 40 shown in phantom lines, and a lower computer cabinet 42 in which a computer controller and image processor 44, preferably an Ultra Sparc AXI 300, available from Sun Micro Systems Corp., is situated. The width and depth dimensions of inspection enclosure 40 are preferably up to about 1.2m width, by 1.0m depth, these dimensions being somewhat larger than the dimensions of typical FPD substrates, however it is readily appreciated that larger dimension may be used in order to accommodate larger substrates. The height of enclosure 40 is preferably 1.00 - 1.30 meters in height, depending on the dimensional constraints of the fabrication equipment in which it is situated.

A stage 46 is situated in the base of the inspection enclosure 40 for supporting an

in-fabrication FPD substrate 24. A non-scanning staring array sensor 48, preferably a CCD type non-scanning staring area camera having between 1,200 X 1000 and 1,500 X 1000 pixel resolution, is secured to enclosure 40 overhead of stage 46. Sensor 48 is preferably a Hammamatsu C4742-95 CCD camera, provided with a wide angle lens, preferably a Nikkor AF 20mm lens from Nikon Corporation. As is readily appreciated, the camera and lens arrangement require a field of view that is sufficient to view at least a substantial part of the substrate 24, and preferably the entire substrate. As will be discussed in detail below with reference to Fig. 11, alternatively, an array of non-scanning sensors that together image the entire substrate, may be provided.

In accordance with a preferred embodiment of the present invention, the sensor 48 is horizontally mounted on top of enclosure 40, and is provided with a flat specular angularly adjustable mirror 50, configured to direct an image of a substrate 24 into the sensor. It is readily appreciated that due to dimensional constraints on the height of enclosure 40 imposed by dimensional limitations of fabrication equipment 12 in which it is situated, it may be advantageous to locate sensor 48 elsewhere in the enclosure and to use mirrors to fold the optical path. For example, an upward staring sensor positioned adjacent to the stage may be used in combination with a substantially downward reflecting mirror to effectively increase the distance between the sensor and the stage without having to increase the height of enclosure 40.

The walls of enclosure 40 are preferably constructed of metal, such as aluminum, and are provided with a black matte coating. A small access opening (not shown) is provided so that fabrication substrates 24 can be readily positioned on stage 46, or removed therefrom.

An array of illumination units 60 is provided inside enclosure 40, for providing various selectable combinations of illumination, as will be explained in greater detail below. In accordance with a preferred embodiment of the present invention, each illumination unit 60 shown in Fig. 4 comprises a housing 62, a cold cathode lamp 64 located inside the housing, a

power supply 66 and a diffuser 68. It is readily appreciated that instead of a wide visible spectrum cold cathode lamps, illumination units 60 may instead employ arrays of individually controllable LEDs configured to provide selectable combinations of wide spectrum or narrow spectrum illumination, flash units, or non-visible spectrum irradiators such as those providing illumination in the near UV spectral region. The diffuser 68 may be formed of a ground glass diffusing element, Fresnel diffuser or similar type diffusing elements.

As shown in Fig. 3, one wall of the inspection enclosure is preferably provided with a first illumination array, referred to herein as tall wall illumination array 70, beginning about 1 cm above stage 46, ranging between 1.00 meter to 1.30 meters in height above the stage, and covering substantially the entire width of an inside wall of the cabinet. Tall wall illumination array 70 is preferably divided into at least 10 individually controllable illumination units 60. A second illumination array, between 35 - 70 cm in height, referred to herein as short wall illumination array 72, is preferably provided on an inside wall of the enclosure 40, typically orthogonal to tall wall illumination array 70.

Short wall illumination array 72 preferably covers substantially the entire width of an inside wall of enclosure 40, preferably beginning at between 8 to 15 cm above the stage, and preferably comprises at least five individually controllable illumination units 60. A third illumination array, referred to as strip illumination array 74, preferably comprises a single independently controllable illumination unit 60. Strip illumination 74 preferably is situated on an inside wall of enclosure 40 typically opposite tall wall illumination array 70, at height of between 5 - 10 cm above the stage 46.

Referring now to Fig. 5, it is seen that the horizontal inclination of stage 46 is preferably selectively adjustable to be at an angle θ relative to the horizontal in either the X - Z plane or Y - Z plane, as shown. Inclination of stage 46 may be selected using a linear positioning table, preferably a model 404XR table available from Daedal. A, rotational positioning of stage 46

relative to its central axis 75 may be adjusted using conventional rotational positioning table means (not shown).

The advantage of providing an array of separately controllable illumination elements 60 for illuminating the stage from different angles in combination with a spatially positionable stage 46 is that the angles of illumination between respective illumination units and the stage and between the stage and sensor 48 may thus be selected both to maximize the contrast of process flaws in matrix 25 relative to substrate 24 and to minimize noise, such as the reflection of an image of sensor 48 back through its lens. For example, some process flaws may be better viewed when illuminated by a substantially bright field illumination. Other types of process flaws may be better viewed when illuminated by dark field illumination provided at various angles to the substrate. It is readily appreciated that in providing a large selection of illumination combinations and of spatial positioning of the stage, the contrast of different flaws can be maximized and noise minimized so as to enhance the ease of viewing various types of process flaws.

The operation of a preferred embodiment of the invention for various combinations of illumination and spatial positioning of the substrate 24, will now be described with reference to Figs. 6 - 8.

In a first illumination configuration, shown in Fig. 6, substantially bright field illumination is provided. Here it is seen that rays 80, geometrically representing the bright field illumination, are reflected by a surface 82 shown to be perfectly spectrally reflecting, such that for such a perfectly spectrally reflecting surface the rays follow a path into a lens 84 of sensor 48 to form a highly substantially uniformly intense flood of light in the lens. It is appreciated that while this illumination is referred to herein as substantially bright field, in fact even for a clean and properly fabricated FPD substrate 24 (Fig. 3), the result is not a perfect uniform spectral reflection because the matrix structure 25 (Fig. 2) deposited on the substrate at least partially

scatters the light. Consequently, patterns will be formed in the reflection that result from non spectral reflection corresponding to light scattered by the pattern deposited on the substrate.

In order to achieve such substantially bright field illumination, stage 46 is inclined toward the tall wall illumination array 70, preferably at an angle α of between 18°- 26°. Preferably all of illumination units 60 of the tall wall illumination array 70 are illuminated simultaneously. Surface 82 is imaged by sensor 48, and the acquired image is subsequently processed by computer controller and image processor 44.

It is appreciated that in the substantially bright field configuration described, each individual point on the stage may be considered as being illuminated by numerous point sources originating in tall wall illumination array 70, and that each individual point source in tall wall illumination 70 may be considered as illuminating numerous points on the surface 82. The result is an intense flood of multi-source illumination on the surface 82.

It is also appreciated that while it is convenient to refer to such illumination as "bright field illumination", in fact some of the illumination is not reflected into lens 84 of sensor 48. The non-bright field illumination can be generally considered "wasted" light that generally does not have a material affect on bright field imaging. Nevertheless, in order to ensure that secondary reflections of the non bright field illumination do not result in undesired noise, internal walls of enclosure 40 are preferably provided with a conventional anti-reflection coating 86.

Additional illumination configurations, shown in Figs. 7 and 8, provide dark field illumination. As seen in Figs. 7 and 8 a ray 88, geometrically representing illumination reflected by a spectrally reflecting surface 90, such as a clean and properly fabricated FPD substrate 24 (Fig. 3), follows a path that does not enter the lens 84 of sensor 48.

In a first dark field illumination configuration, shown in Fig. 7, stage 46 is inclined away from tall wall illumination array 70, preferably at an angle β, ranging between 12° - 18° relative

to the horizontal, so that an image of sensor 48 is not reflected by surface 90 back into lens 84. Initially, illumination is provided by predetermined combinations of illumination units 60 forming part of tall wall illumination array 70. The units 60 in tall wall illumination array 70 that are employed for this purpose are preferably located between 5 – 50 cm above stage 46. The inclination of stage 46 and the angle of the illumination are selected to provide dark field illumination of at least part of surface 90. The surface 90 is imaged by sensor 48 for each of a plurality of different illumination configurations. If a given illumination configuration does not provide dark field illumination of the entire surface 90, stage 46 may be rotated as necessary. Preferably, a second combination of dark field illumination is provided in which the units 60 that are located in the range of 40 – 90 cm above stage 46 are employed to illuminate the at least part of surface 90.

In a similar manner, preferably dark field illumination is additionally provided by illumination units 60 forming part of short wall illumination array 72.

Referring now to Fig. 8, there is seen a dark field illumination configuration employing a strip illuminator 74 (Fig. 3) . The stage is inclined at angle β, preferably between 12° - 18° relative to the horizontal, away from the tall wall illumination array 70 and toward strip illuminator 74. A blind 94 is preferably provided to adjust the width of illumination emanating from strip illuminator 74 to between 5 – 12 cm. It is readily appreciated that instead of a blind, a narrow illumination source may be provided as strip illuminator 74. It is seen that if an inspected surface 96 supported on stage 46 (Fig. 3) is inclined toward strip illuminator 74, the strip illuminator 74 provides illumination at a sufficiently low angle of incidence relative to surface 96 such that the illumination does not reflect into lens 84 sensor 48, and thus provides dark field illumination.

It is appreciated that the illumination configurations are preferably determined empirically to maximize the contrast of various defects on substrate 24, and minimize undesired

reflections therefrom.

Reference is now made to Fig. 9, which illustrates the structure of an optical head 100 suitable for use in the present invention. Optical head 100 preferably comprises a non-scanning sensor 102, a mirror 104, a plurality of optical filters 106, a mechanical driver 108 for changing optical filters 106, and a blur generator 110. Preferably, the plurality of filters 106 includes both polarization and spectral filters. Substrate 24 (Fig. 3) is preferably imaged using various different combinations of filters 106 to acquire a series of broad spectrum, narrow spectrum and polarized light images. The angular orientation of mirror 104 may be adjustable as shown, to enable imaging of various parts of the substrate or to minimize reflection of images of optical head 100 by the substrate 24 (Fig. 3).

Preferably, during imaging, blur generator 110 is operative to introduce blurring in the image acquired by sensor 102 . Blurring is effective to attenuate the Moire effect arising from resolution differences between sensor 102 and the pattern deposited on the substrate 24 (Fig. 3). The blurring may be achieved by means of mechanical vibration that is operative to cause relative displacement between sensor 102, and/or mirror 104 and/or stage 46 (Fig. 3) and/or any other optical element situated along the optical path between the sensor and the stage. Alternatively, blurring may be introduced by an optical blurring filter or by electronic manipulation of the image signal.

Reference is now made to a simplified flow chart illustrating operation of part of a system, such as the system of Fig. 1 for FPD fabrication. The flowchart of Fig. 10 illustrates steps of performing a fabrication process on a substrate and inspecting the substrate. The operation illustrated in Fig. 10 identifies fabrication process flaws while an in-fabrication FPD substrate is still within a self-contained environment of fabrication equipment 12 (Fig. 1), and before the substrate is transferred to other equipment that performs downstream fabrication steps.

As shown in Fig. 10, the following steps are preferably performed:

STEP 160: A cassette 20 (Fig. 1) containing FPD substrates 24 (Fig. 3) is placed in fabrication equipment 12 (Fig. 1) that has a self-contained micro environment having a level of airborne contamination substantially lower than the level of airborne contamination in a surrounding clean room 13 (Fig. 1).

STEP 180: A series of fabrication process steps is sequentially performed on the each of substrates 24. By way of example only, a series of steps performed in particular equipment may include the deposition a photoresist film over a thin metallic film previously deposited on a substrate 24, exposure of the photoresist in a predetermined pattern using conventional stepper equipment, subsequent development of the photoresist and washing away unexposed photoresist to leave on the substrate a patterned deposit of photoresist. Alternatively, any other suitable series of predetermined process steps may be performed.

STEP 200: After completion of the various fabrication process steps performed on a substrate 24 in the equipment 12, and prior to its transfer to other equipment for subsequent fabrication processing, the substrate is positioned on stage 46 (Fig. 3) for conducting process flaw inspection inside the self-contained micro-environment of equipment 12. It is readily appreciated that because substrates 24 do not have to be removed from the equipment 12 for inspection, it is not necessary to wait for the completion of fabrication processes on an entire batch. Thus, preferably, each substrate is inspected one by one immediately upon its having completed predetermined processes, while fabrication processes simultaneously continue for other substrates in the batch until all substrates have been processed and inspected.

STEP 210: The spatial orientation of stage 46 is adjusted to position the substrate in a predetermined position for substantially bright field illumination or for one of the dark field illumination combinations. As necessary to eliminate reflection and to aim the field of view of sensor 48 (Fig. 3) to a desired part of substrate 24 that is to be inspected, the angular orientation

of mirror 50 (Fig. 3) is adjusted.

STEP 220: A predetermined combination of illumination units 60 (Fig. 3) is activated to illuminate the substrate. The illumination may be substantially bright field illumination, or any combination of dark field illumination as described above.

STEP 230: An image of the substrate is acquired in a digitized form by sensor 48 and channeled to computer image processor 44 (Fig. 3) through frame grabber hardware and software (not shown) such as a PCI DV frame grabber system, available from EDT, Inc. of Oregon. Preferably, a single full frame image of the substrate is acquired.

STEP 240: The image acquired in step 230 is analyzed for fabrication process defects using image analysis techniques more fully described in U.S. Patent 5,771,068, to the present assignee, the disclosure of which is hereby incorporated by reference. Preferably, these techniques include edge definition and registration functions, and are augmented by fine feature detection techniques for identifying particles and lines such as scratches and rinse tracks. Suitable fine feature detection can be adapted from the ultra fine defect detection described in detail in US patent 5,586,058, incorporated herein by reference.

It is a particular feature of the preferred embodiments of the image acquisition and analysis system that image analysis is preferably performed without reference to an external reference.

Because a properly fabricated substrate should be comprised of evenly deposited films and should not have any residues, streaks, scratches, particles or other similar anomalies thereon, fabrication process flaws can be identified as being areas on the substrate whose reflected intensities differ from those of surrounding areas by an amount less than or greater than a predetermined standard deviation.

STEP 250: If additional combinations of illumination are required, steps 210 - 240 are repeated.

STEP 260: Upon acquisition and analysis of all desired images, a determination is made, using computer image processor 44, whether process defects exist on the substrate. The determination may be made for each substrate, and information about defects may be fed into a data base of defects. Substrates found to contain fabrication process defects may be marked as defective and removed for repair or discarded so that further processing resources will not be wasted on a defective substrate until after it is repaired.

The close temporal proximity of detection of fabrication process flaws to completion of a set of process steps provided by the present invention enables close monitoring of the production and control conditions under which equipment 12 fabricates substrates. Thus, computer 44 is preferably programmed to provide an alarm, or in extreme conditions to shut down equipment, when defective substrates are being produced.

For example, computer controller and image processor 44 may be tailored to selectively provide an alert or shut down the equipment depending on the nature of the flaw. Thus, if a particular flaw, such as a scratch, that necessitates the discarding of affected substrates, occurs in a predetermined number of sequential substrates, such as three substrates, then the computer controller may automatically shut off the defective equipment to prevent production of additional defective substrates. However, if a less critical flaw, for example the presence of a rinse residue, occurs a number of times but non-sequentially, then the affected substrates can be set aside for repair and an appropriate alert may be made so that the machine can be repaired or adjusted when convenient.

It is appreciated that the system whose operation is described hereinabove with reference to Fig. 10 provides considerable flexibility in determining the particular combination of conditions under which affected equipment is shut down, or an alert is provided.

STEP 280: Those substrates which have been determined not to be flawed are placed in cassettes and removed from the self-contained micro-environment of the equipment, and are

transferred other equipment for the next stage of processing and inspection . Those substrates which have been classified as having repairable flaws may be transferred to a suitable repair station, before subsequent process stages are performed.

Reference is now made to Fig. 11 which illustrates additional features of preferred embodiments of the present invention. Instead of a single sensor 48 as in the embodiment of Fig. 3, here a plurality of non-scanning staring array sensors 148 is shown. Each of the plurality of sensors 148 preferably images a part of a substrate 150. Joining of images produced by each sensor 148 preferably produces a complete image of substrate 150. This arrangement of sensors 148 enables the processing of a relatively large substrate without losing resolution or substantially increasing the height of an enclosure 152, which encloses the inspection region.

Illumination may be provided by illuminators 160. Illuminators 160 are preferably provided with reflectors 162 to direct illumination onto substrate 150, and are preferably pivotably mounted on pivots 164. Drivers (not shown) may be provided to enable tilting of the illuminators 160 and to enable the illumination therefrom to be selectively directed. The illuminators 160 may optionally be provided with diffusers or filters 166.

Another alternative preferred embodiment of the invention is illustrated in Fig. 12. In this embodiment, an inspection system 200 constructed and operative in accordance with a preferred embodiment of the present invention is preferably located inside a self-contained ultra-clean micro environment 202 of fabrication equipment 204, which is located inside a clean room area 206 of a fabrication facility, such as fabrication facility 10 (Fig. 1). It is a particular feature of this embodiment that the inspection system is connected to a controller 208, situated outside the clean room area 206, preferably by means of a cable 210, and manually operated by a human operator, preferably using a display 212.

Images of FPD substrates acquired by a sensor in the inspection system 200, may be viewed on display 212, and illumination combinations and camera-substrate angles may be

determined by a set routine or controlled by the operator, for example using a joystick 214 or by choosing positions from a predetermined set. It is appreciated, that the inspection system of Fig. 12 provides for close human control of fabrication and inspection by a remotely located operator, and represent a dramatic improvement over systems that require the physical presence of numerous human inspectors inside clean room areas.

It is appreciated that the particular embodiments described herein are intended to be a detailed disclosure of the invention, and are not intended to be limiting. While various of the features have been described for clarity in the context of separate embodiments, these features may also be provided in a single embodiment. Conversely, various features which have been described in the context of a single embodiment may also be provided separately or in a suitable alternative combination.

It should be also be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes combinations and subcombinations of various features described hereinabove as well as modifications and additions thereto which would occur to a person of skill in the art upon reading the foregoing description and which are not in the prior art.

CLAIMS

1. A system for manufacture of flat panel displays comprising:

a plurality of manufacturing devices located in a first controlled airborne particle contamination environment, at least some of said plurality of manufacturing devices each including an enclosure defining a second controlled airborne particle contamination environment having a lower level of contamination than that of said first controlled airborne particle contamination environment; and

a plurality of optical inspection devices operative to inspect flat panel display substrates at various stages of the production thereof by said plurality of manufacturing devices, at least some of said plurality of optical inspection devices being located within said enclosures defining said second controlled airborne particle contamination environments.

2. A system for manufacture of flat panel displays according to claim 1 and wherein said plurality of optical inspection devices are operative in coordination with said plurality of manufacturing devices for inspecting said substrates prior to transfer thereof out of said second controlled airborne particle contamination environment.

3. A system for manufacture of flat panel displays according to either of the preceding claims and wherein at least some of said plurality of optical inspection devices comprise non-scanning sensors.

4. A system for manufacture of flat panel displays according to any of the preceding claims and wherein said plurality of optical inspection devices are operative to identify fabrication process defects occurring during production of flat panel display substrates.

5. A system for manufacture of flat panel displays according to claim 4 and wherein said process defects include at least one of the following: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

6. A system for manufacture of flat panel displays according to any of the preceding claims and wherein each of said plurality of optical inspection devices includes at least one non-scanning sensor which views substantially all of the surface of said substrate.

7. A system for manufacture of flat panel displays according to claim 6 and wherein the at least one non-scanning sensor comprises a plurality of non-scanning sensors wherein each sensor views a portion of the substrate and together the plurality of sensors views substantially the entire surface of said substrate.

8. A system for manufacture of flat panel displays according to any of the preceding claims and wherein each of said plurality of optical inspection devices comprises an illuminating array operative to provide various combinations of illumination.

9. A system for manufacture of flat panel displays according to claim 8 in which the combinations include at least dark field and substantially bright field illumination.

10. A system for manufacture of flat panel displays according to claim 8 in which the non-scanning sensor acquires at least one image of the substrate for each combination.

11. A system for manufacture of flat panel displays according to claim 10 and also comprising an image analyzer for identifying process defects by computer analysis of a plurality of image of the substrate taken with various ones of said combinations of illumination.

12. A system for manufacture of flat panel displays according to claim 11 and wherein said image analyzer is operative without comparison to an external reference.

13. A system for manufacture of flat panel displays according to any of the preceding claims and wherein said enclosure contains a first plurality of illuminators mounted on a first wall of said enclosure and a second plurality of illuminators mounted on a second wall of said enclosure, orthogonal to said first wall.

14. A system for manufacture of flat panel displays according to any of the preceding claims and also comprising directionally adjustable illuminators..

15. An inspection system for use in inspecting flat panel displays comprising:

a non-scanning optical array for viewing a flat panel display substrate; and

an illumination subsystem sequentially providing dark field and bright field illumination of said flat panel display substrate when said optical array views said flat panel display substrate.

16. An inspection system according to claim 15 and wherein said illumination subsystem provides various combinations of dark field and bright field illumination of said flat panel display substrate when said optical array views said flat panel display substrate.

17. An inspection system according to claim 16 and also comprising a spatially positionable stage to support the flat panel display substrate, wherein the stage spatially positions the substrate at various angles relative to the illumination subsystem.

18. An inspection system according to claim 17and also comprising an image analyzer receiving an output from said non-scanning optical array and being operative to detect process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

19. An inspection system according to any of claims 16 - 18and wherein said optical array views substantially all of a surface of said substrate.

20. An inspection system according to any of claims –16 - 19 and wherein said optical array acquires at least one image of said substrate for each of a plurality of different illuminations.

21. An inspection system according to claim 18 in which image analyzer identifies said defects by computer analysis of a plurality of images of said substrate taken at differing illumination.

22. An inspection system according to any of claims 16 – 21 and also comprising an

enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

23. An inspection system according to claim 22 and also comprising a third illuminator mounted on a third wall of said enclosure.

24. An inspection system according to any of claims 16 – 23 and also comprising a diffuser associated with said illumination subsystem.

25. An inspection system according to any of claims –16 - 24 and comprising an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of said optical array, said illumination subsystem and said substrate.

26. An inspection system for use in inspecting objects comprising:

a non-scanning optical array for viewing an object; and

an illumination subsystem sequentially providing dark field and bright field illumination of said flat panel display substrate when said optical array views said object.

27. An inspection system according to claim 26 and wherein said illumination subsystem provides various combinations of dark field and bright field illumination of said object when said optical array views said object.

28. An inspection system according to claim 26 or claim 27 and also comprising an image analyzer receiving an output from said non-scanning optical array and being operative to detect process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

29. An inspection system according to any of claims 26 - 28 and wherein said optical array views substantially all of a surface of said substrate.

30. An inspection system according to any of claims 26 - 29 and wherein said optical

array acquires at least one image of said substrate for each of a plurality of different illuminations.

31. An inspection system according to claim 28 in which image analyzer identifies said defects by computer analysis of a plurality of images of said substrate taken at differing illumination.

32. An inspection system according to any of claims 26 - 31 and also comprising an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

33. An inspection system according to claim 32 and also comprising a third illuminator mounted on a third wall of said enclosure.

34. An inspection system according to any of claims 26 - 33 and also comprising a diffuser associated with said illumination subsystem.

35. An inspection system according to any of claims 26 - 34 and comprising an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of said optical array, said illumination subsystem and said substrate.

36. Apparatus for optically inspecting the surface of an article having a substantially planar surface, comprising:

an inspection region;

illumination apparatus to selectably illuminate the surface of an article located in the inspection region with at least two predetermined configurations of illumination;

an image acquisition sub-system comprising at least one non-scanning camera for acquiring images of the surface of the article when illuminated by at least one predetermined configuration of illumination; and

an image analysis subsystem for computer analyzing the images and detecting

anomalies in the surface as a function of variations in reflected intensities of illumination.

37. Apparatus for optically inspecting the surface of an article according to claim 36 and also comprising a spatially positionable stage for supporting the article in the inspection region in selectable orientation relative to the illumination apparatus.

38. Apparatus for optically inspecting the surface of an article according to any of claims 36 – 37, wherein the image analysis subsystem is operative to identify anomalies that are substantially the same size as the resolution of the camera.

39. Apparatus for coating an article having a substantially planar surface, comprising:

a coating generator operative to generate a coating on a surface of the article;

an illuminator for selectably illuminating said surface bearing said coating with at least two predetermined configurations of illumination;

an image acquisition sub-system comprising at least one non-scanning sensor for acquiring images of the surface of the article for each combination of illumination; and

an image analysis subsystem for analyzing the images and detecting anomalies in the surface on the basis of variations in reflected intensities of illumination.

40. Apparatus for inspecting an article in a clean room, comprising:

an inspection device situated in the clean room and including:

an inspection stage selectably positionable by remote control;

at least one non-scanning sensor viewing the substantially the entire inspection stage;

an array of illuminators illuminating the inspection stage;

automated feed apparatus for placing articles in the inspection device;

a remote control situated outside the clean room for viewing articles placed in the inspection device, said remote control comprising a viewer and a controller for remotely positioning the stage and selecting combinations of illumination.

41. A method for manufacture of flat panel displays comprising:

providing a plurality of manufacturing devices located in a first controlled airborne particle contamination environment, at least some of said plurality of manufacturing devices each including an enclosure defining a second controlled airborne particle contamination environment having a lower level of contamination than that of said first controlled airborne particle contamination environment; and

inspecting flat panel display substrates at various stages of the production thereof by said plurality of manufacturing devices at a location within said enclosures defining said second controlled airborne particle contamination environments.

42. A method according to claim 41 and wherein said inspecting step comprises inspecting said substrates prior to transfer thereof out of said second controlled airborne particle contamination environment.

43. A method according to either of claims 41 and 42 and wherein said inspecting step comprises inspecting using non-scanning sensors.

44. A method according to any of claims 41 - 43 and further comprising identifying fabrication process defects occurring during production of flat panel display substrates.

45. A method according to claim 44 and wherein said identifying step comprises identifying process defects including at least one of the following: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

46. A method according to any of claims 41 - 45 and wherein said inspecting step comprises inspecting using at least one non-scanning sensor which views substantially all of the surface of said substrate.

47. A method according to claim 46 and wherein said inspecting step comprises inspecting using a plurality of non-scanning sensors wherein each sensor views a portion of the

substrate and together the plurality of sensors views substantially the entire surface of said substrate.

48. A method according to any of claims 41 - 47 and wherein said inspecting step comprises illuminating the substrate with an illuminating array operative to provide various combinations of illumination.

49. A method according to claim 48 in which the combinations include at least dark field and substantially bright field illumination.

50. A method according to claim 48 and wherein said inspecting step comprises acquiring at least one image of the substrate for each combination using said non-scanning sensor.

51. A method according to claim 50 and also comprising image-analyzing the process defects by computer analysis of a plurality of images of the substrate taken with various ones of said combinations of illumination.

52. A method according to claim 51 and wherein said image-analyzing step is performed without comparison to an external reference.

53. A method according to any of claims 41 - 52 and wherein said providing step comprises further providing said enclosure with a first plurality of illuminators mounted on a first wall of said enclosure and a second plurality of illuminators mounted on a second wall of said enclosure, orthogonal to said first wall.

54. A method according to any of the preceding claims 41 - 53 and wherein said providing step comprises further providing directionally adjustable illuminators.

55. A method for inspecting flat panel displays comprising:

viewing a flat panel display substrate using a non-scanning optical array; and

sequentially illuminating said flat panel display substrate with dark field and bright field illumination when said optical array views said flat panel display substrate.

56. A method according to claim 55 and wherein said sequentially illuminating step illuminates using various combinations of dark field and bright field illumination of said flat panel display substrate when said optical array views said flat panel display substrate.

57. A method according to claim 56 and also comprising

supporting the substrate with a spatially positionable stage, and spatially positioning the stage at various angles to illuminate the substrate with dark field and bright field illumination.

58. A method according to claim 56 or claim 57 and also comprising:

receiving an output from said non-scanning optical array; and

detecting process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

59. A method according to any of claims 55 - 58 and wherein said viewing step comprises viewing substantially all of a surface of said substrate.

60. A method according to any of claims 55 - 59 and wherein said viewing step comprises acquiring at least one image of said substrate for each of a plurality of different illuminations.

61. A method according to claim 58 and wherein said detecting step comprises identifying said defects by computer analysis of a plurality of images of said substrate taken at differing illumination.

62. A method according to any of claims 55 - 61 and also comprising providing an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

63. A method according to claim 62 and wherein said providing step also comprises providing a third illuminator mounted on a third wall of said enclosure.

64. A method according to any of claims 55 - 63 and also comprising providing a diffuser associated with said illumination subsystem.

65. A method according to any of claims 55 – 64 and also comprising providing an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of said optical array, said illumination subsystem and said substrate.

66. A method for inspecting objects comprising:

viewing an object using a non-scanning optical array; and

sequentially illuminating said object with dark field and bright field illumination when said optical array views said object.

67. A method according to claim 62 and wherein said sequentially illuminating step illuminates using various combinations of dark field and bright field illumination of said object when said optical array views said object.

68. A method according to claim 67 and also comprising:

receiving an output from said non-scanning optical array; and

detecting process defects including at least one of: uneven deposition of coatings, uneven removal of coatings, rinse residues, chemical residues, incomplete exposure of a photo-resist deposited on the substrate, scratches, lines, particles.

69. A method according to any of claims 66 – 68 and wherein said viewing step comprises viewing substantially all of a surface of said object.

70. A method according to any of claims 66 – 69 and wherein said viewing step comprises acquiring at least one image of said object for each of a plurality of different illuminations.

71. A method according to claim 68 and wherein said detecting step comprises identifying said defects by computer analysis of a plurality of images of said object taken at

differing illumination.

72. A method according to any of claims 66 – 71 and also comprising providing an enclosure containing a first plurality of illuminators mounted on one wall thereof and a second plurality of illuminators mounted on a second wall thereof.

73. A method according to claim 72 and wherein said providing step also comprises providing a third illuminator mounted on a third wall of said enclosure.

74. A method according to any of claims 66 – 73 and also comprising providing a diffuser associated with said illumination subsystem.

75. A method according to any of claims 66 – 74 and also comprising providing an adjustable mounting assembly for selectably determining at least one of relative inclination, spatial separation and axial orientation of at least two of said optical array, said illumination subsystem and said object.

76. A method for optically inspecting the surface of an article having a substantially planar surface, comprising:

defining an inspection region;

selectably illuminating the surface of an article located in the inspection region with at least two predetermined configurations of illumination;

acquiring images of the surface of the article when illuminated by at least one predetermined configuration of illumination using at least one non-scanning camera; and

analyzing the images and detecting anomalies in the surface as a function of variations in reflected intensities of illumination.

77. A method for optically inspecting the surface of an article according to claim 76 and also comprising supporting the article on a spatially positionable stage in the inspection region, and selectably spatially orienting the stage relative to a predetermined configuration of illumination.

78. A method for optically inspecting the surface of an article according to claim 76 or 77, wherein the analyzing step is operative to identify anomalies that are substantially the same size as the resolution of the non-scanning camera.

79. A method for coating an article having a substantially planar surface, comprising:

generating a coating on a surface of the article;

selectably illuminating said surface bearing said coating with at least two predetermined configurations of illumination;

acquiring images of the surface of the article for each combination of illumination using at least one non-scanning sensor; and

analyzing the images and detecting anomalies in the surface on the basis of variations in reflected intensities of illumination.

80. A method for inspecting an article in a clean room, comprising:

situating an inspection device in the clean room;

selectably positioning an inspection stage of said inspection device by remote control;

viewing substantially the entire inspection stage using at least one non-scanning sensor of said inspection device;

illuminating the inspection stage using an array of illuminators of said inspection device;

placing articles in the inspection device using automated feed apparatus of said inspection device; and

situating a remote controller outside the clean room for viewing articles placed in the inspection device, said remote controller comprising a viewer and a controller for remotely positioning the stage and selecting combinations of illumination.

81. A method for inspecting the surface of an article, comprising the steps of:

placing the article in an inspection region defined by a stage;

illuminating a portion of the surface of the article with at least one configuration of dark field illumination;

acquiring an image of substantially the entire surface for the at least one configuration of dark field illumination;

illuminating the surface with at least one configuration of substantially bright field illumination;

acquiring an image of substantially the entire surface for the at least one configuration of substantially bright field illumination;

computer analyzing the images to determine non uniformities in reflected intensities.

82. The method of claim 81in which the at least one configuration of dark field illumination comprises a plurality of dark field illumination combinations, and separate images are acquired for each of the combinations.

83. The method of claim 81 in which the at least one configuration of substantially bright illumination comprises a plurality of bright field illumination combinations, and separate images are acquired for each of the combinations.

84. The method of claim 83 comprising the additional step for each predetermined combination of illumination of selecting a predetermined inclination and orientation of the substrate, and acquiring separate images of the surface for each said inclination and axial orientation.

85. The method of claim 81 comprising the additional step of optically treating the illumination prior to acquiring an image.

86. The method of claim 85 in which the treatment is provided by optical filters.

87. The method of claim 86 in which the filters filter for selected wavelengths.

88. The method of claim 86 in which the filters filter for selected polarization.

89. The method of claim 85 in which the surface is illuminated with a selected combination of broad spectrum illumination and imaged with filtered illumination in a first predetermined spectral range, and subsequently imaged with filtered illumination in a second predetermined spectral range.

90. The method of claim 85 in which the surface is illuminated with a first combination of filtered illumination in a predetermined spectral range and imaged, and subsequently illuminated with a second combination of illumination in a predetermined spectral range and imaged.

91. The method of claim 85 in which the surface is illuminated with a selected combination of broad spectrum illumination and imaged with filtered illumination in a first predetermined polarization, and subsequently imaged with filtered illumination in a second predetermined polarization.

92. The method of claim 85 in which the surface is illuminated with a first combination of filtered illumination in a predetermined polarization and imaged, and subsequently illuminated with a second combination of illumination in a predetermined polarization and imaged.

93. The method of claim 81 comprising the additional step of blurring the image during acquisition.

94. The method of claim 93 in which the at least one image is blurred by introducing relative movement between at least two of the following: the surface, the camera, and an optical element between the surface and the camera.

95. The method of claim 81 comprising the further step of computer analyzing said non-uniformities to determine the presence of defects in coatings on the substrate.

96. The method of claim 81 in which the article is a flat display panel substrate.

97. A method for coating the surface of an article with a film, comprising the steps of:

depositing a film coating on at least part of a surface of the article; placing the article in an inspection region;

illuminating a portion of the coated surface of the article with at least one configuration of dark field illumination;

acquiring an image of the surface illuminated by the at least one configuration of dark field illumination;

illuminating the surface with at least one configuration of substantially bright field illumination;

acquiring an image of the entire surface illuminate by the least one configuration of substantially bright field illumination;

computer analyzing each image to determine non uniformities in reflected intensities.

For the Applicant,

Sanford T. Colb & Co.
C:31323

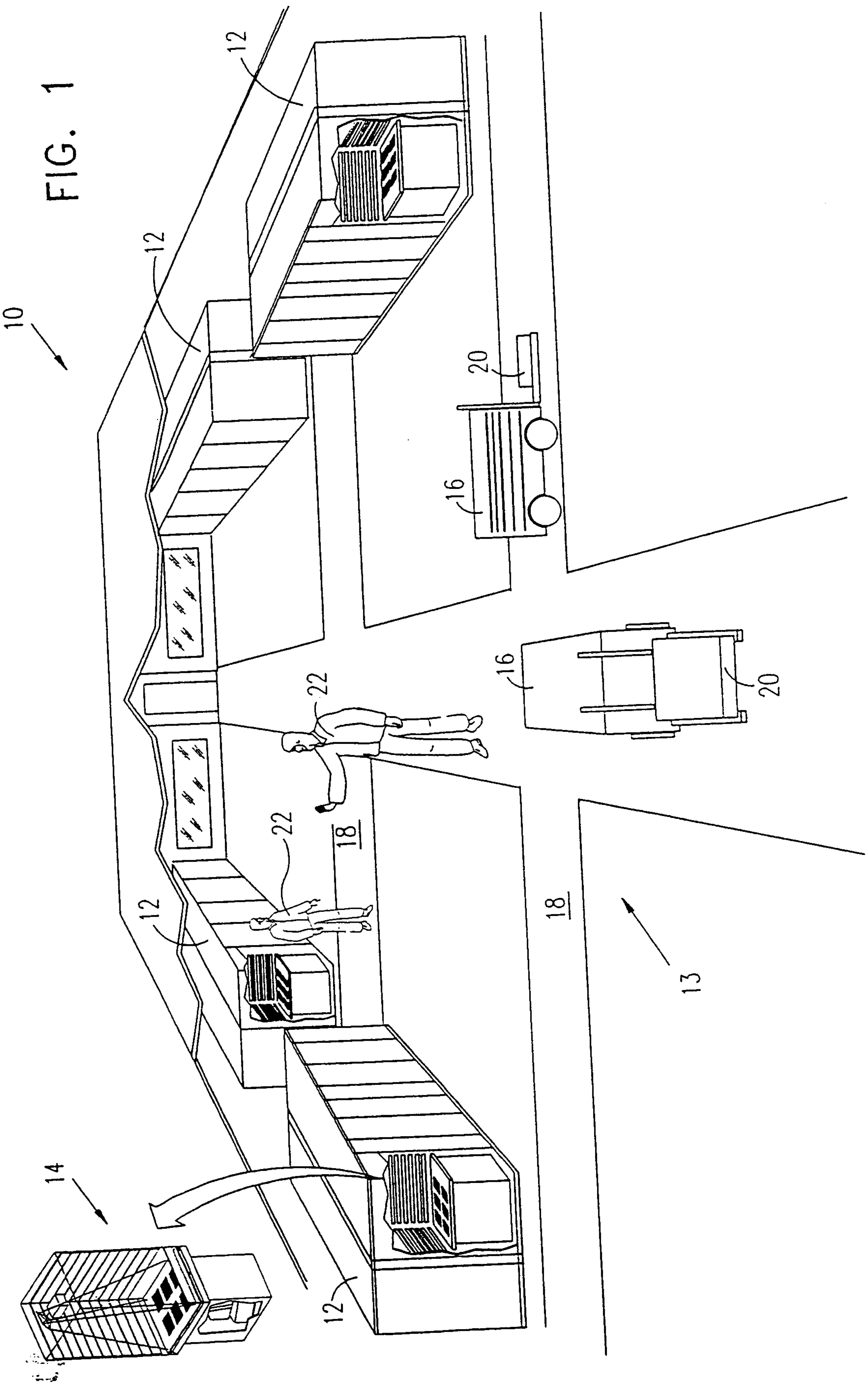


FIG. 1

FIG. 2A

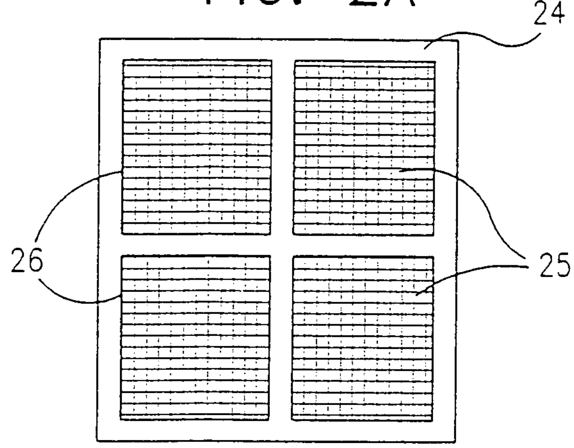


FIG. 2B

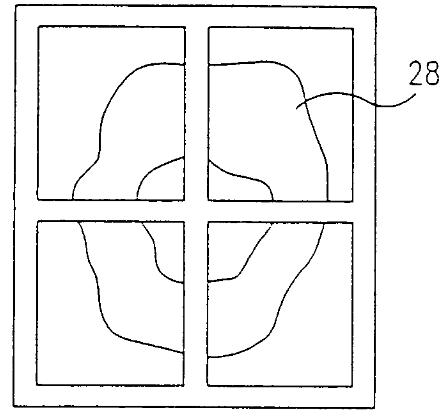


FIG. 2C

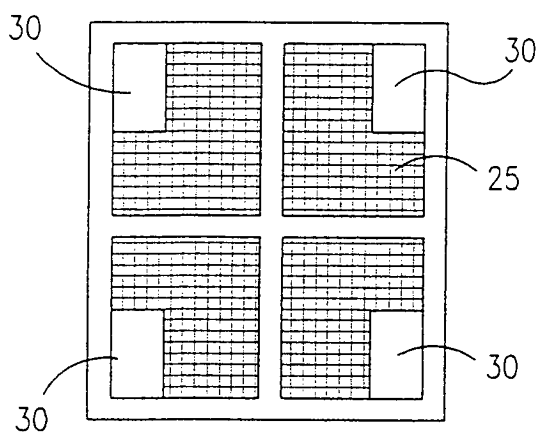


FIG. 2D

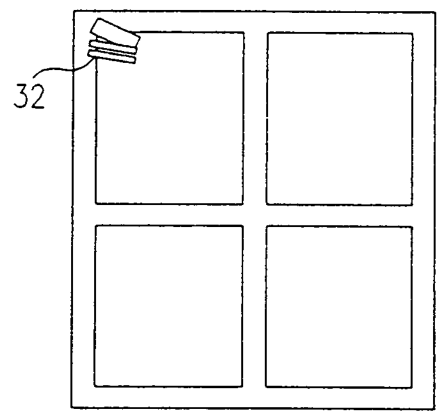
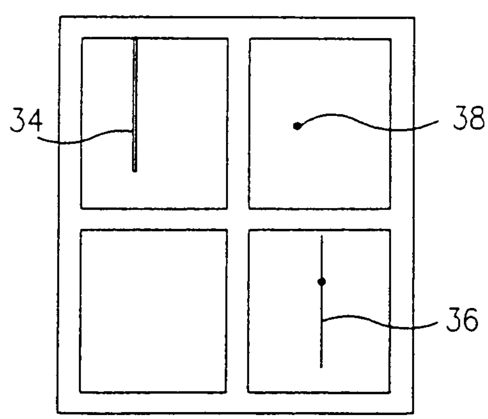


FIG. 2E



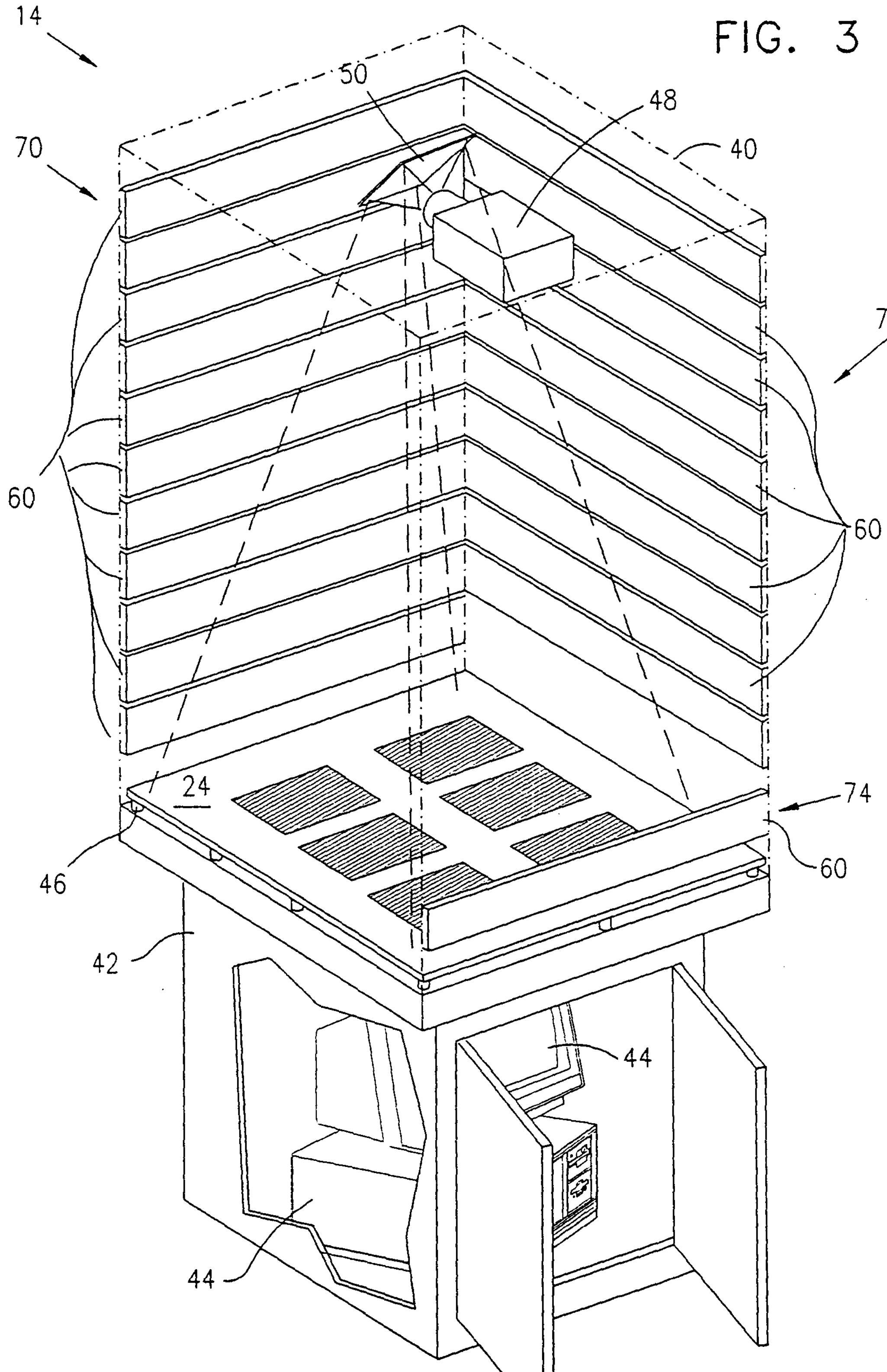
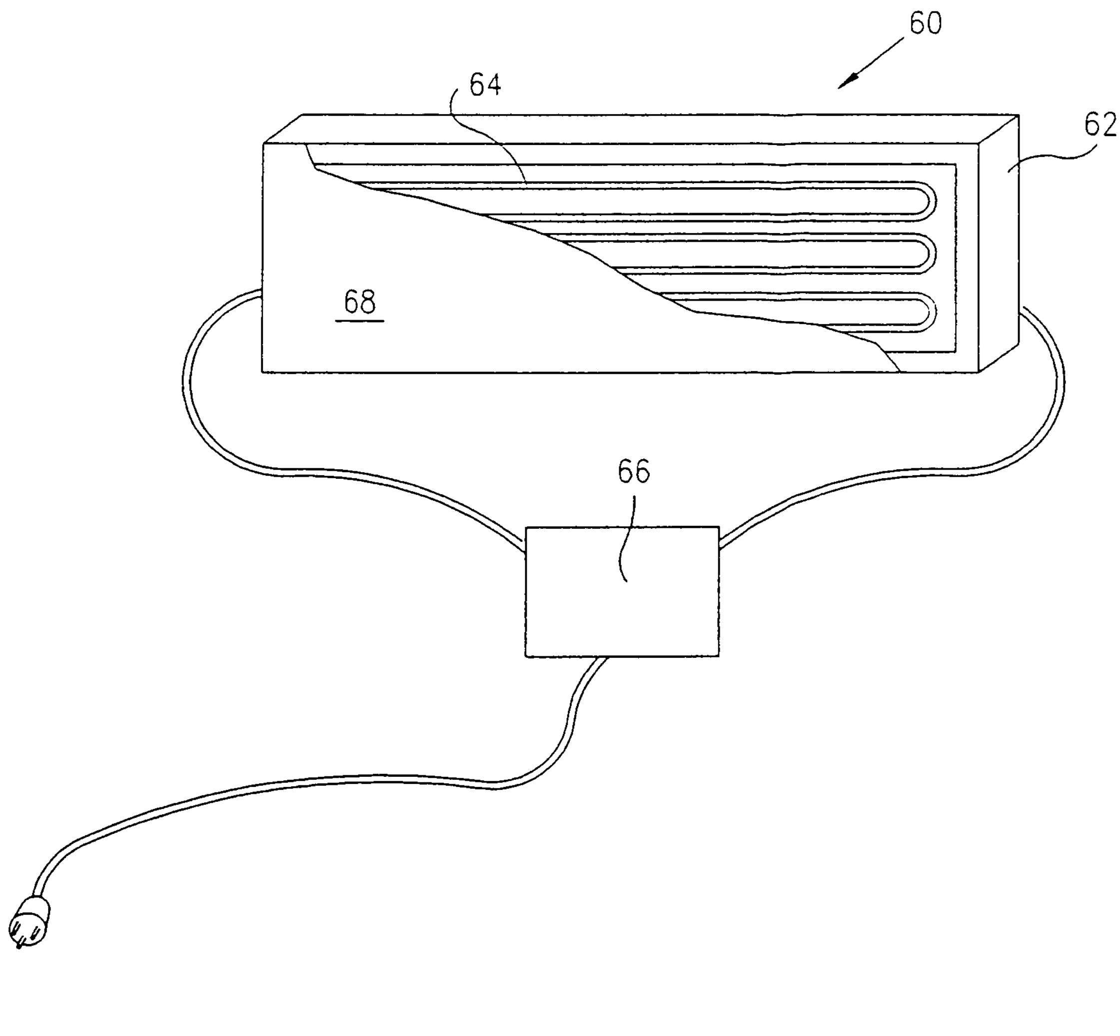


FIG. 3

FIG. 4



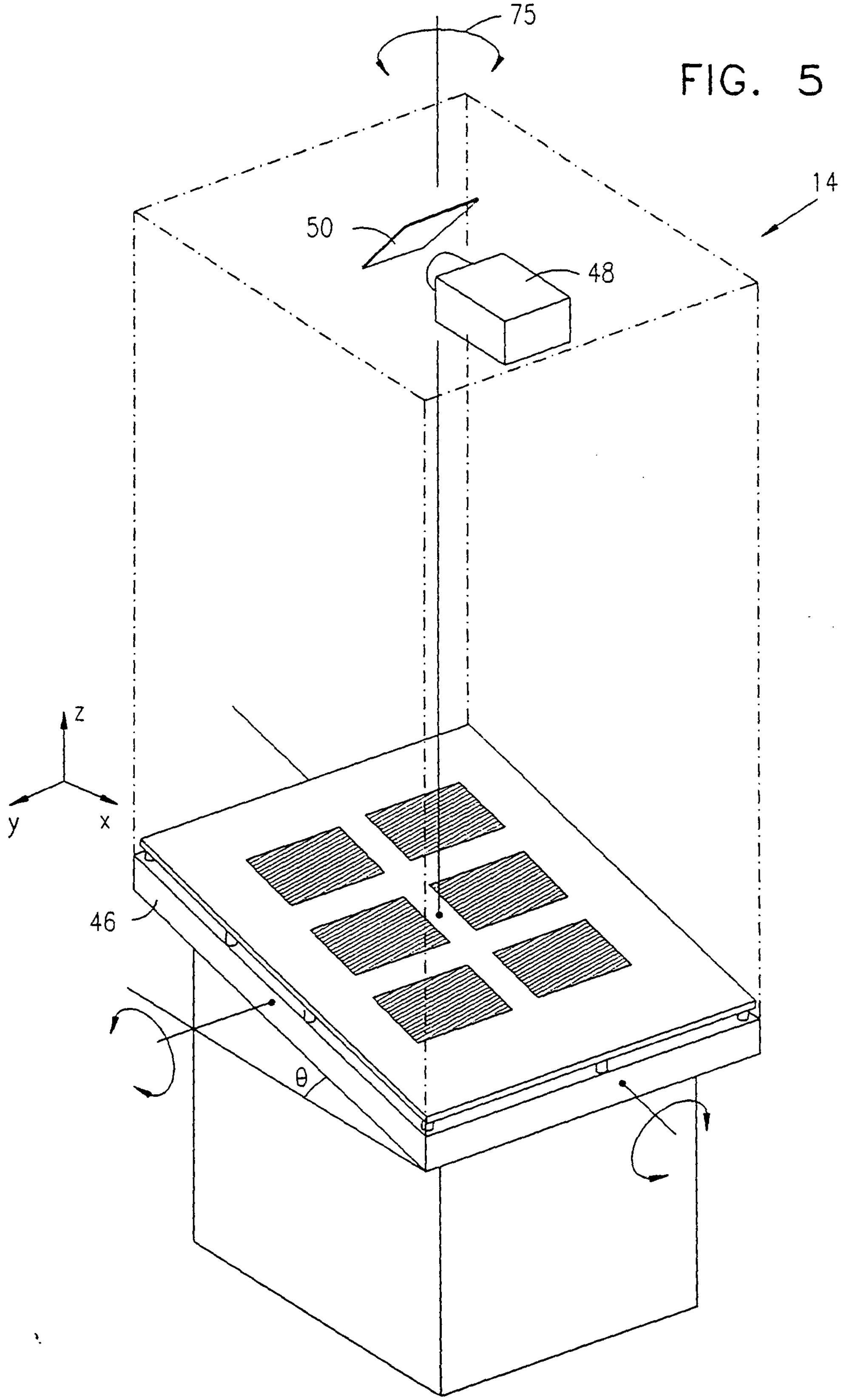


FIG. 5

FIG. 6

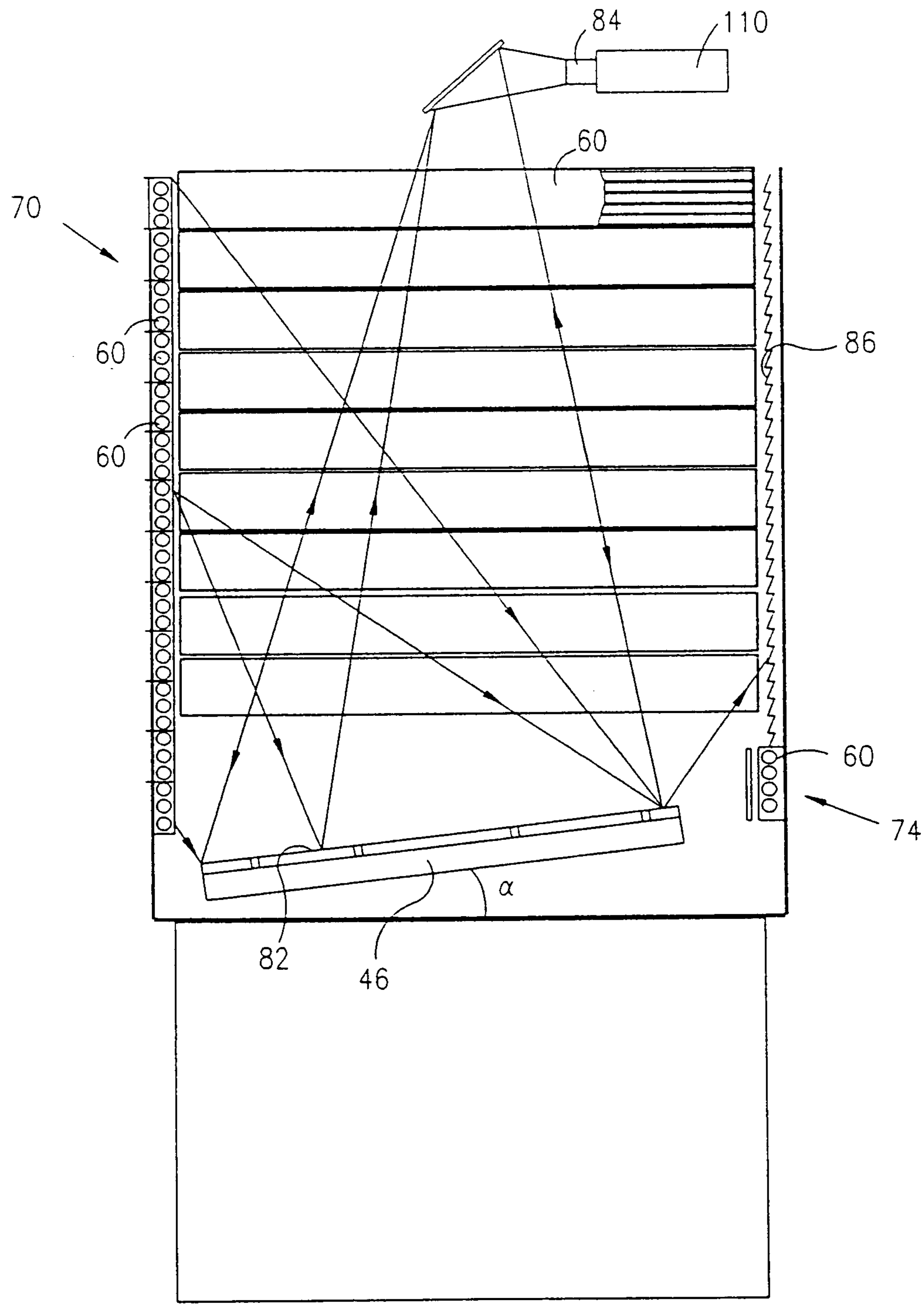


FIG. 7

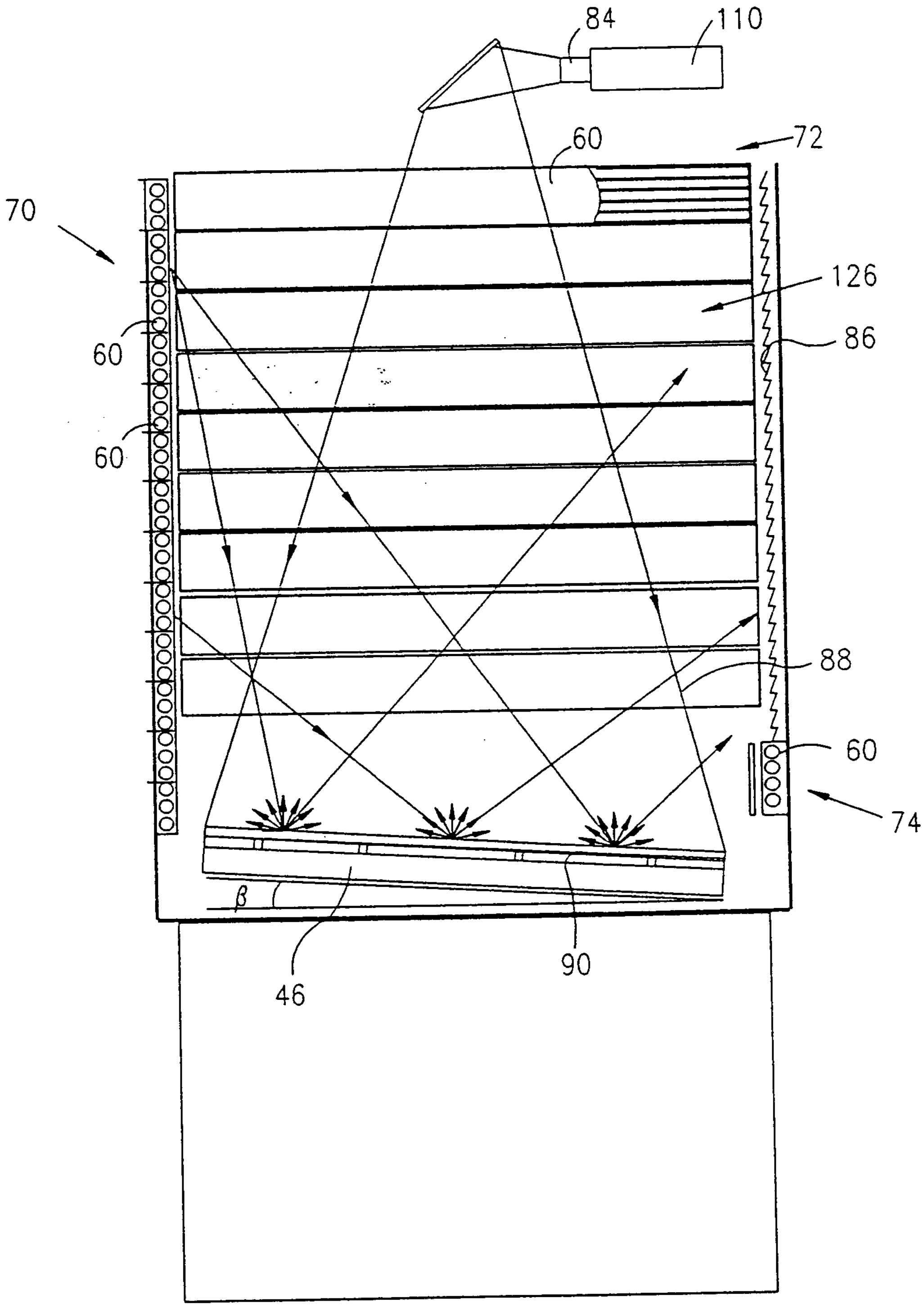


FIG. 8

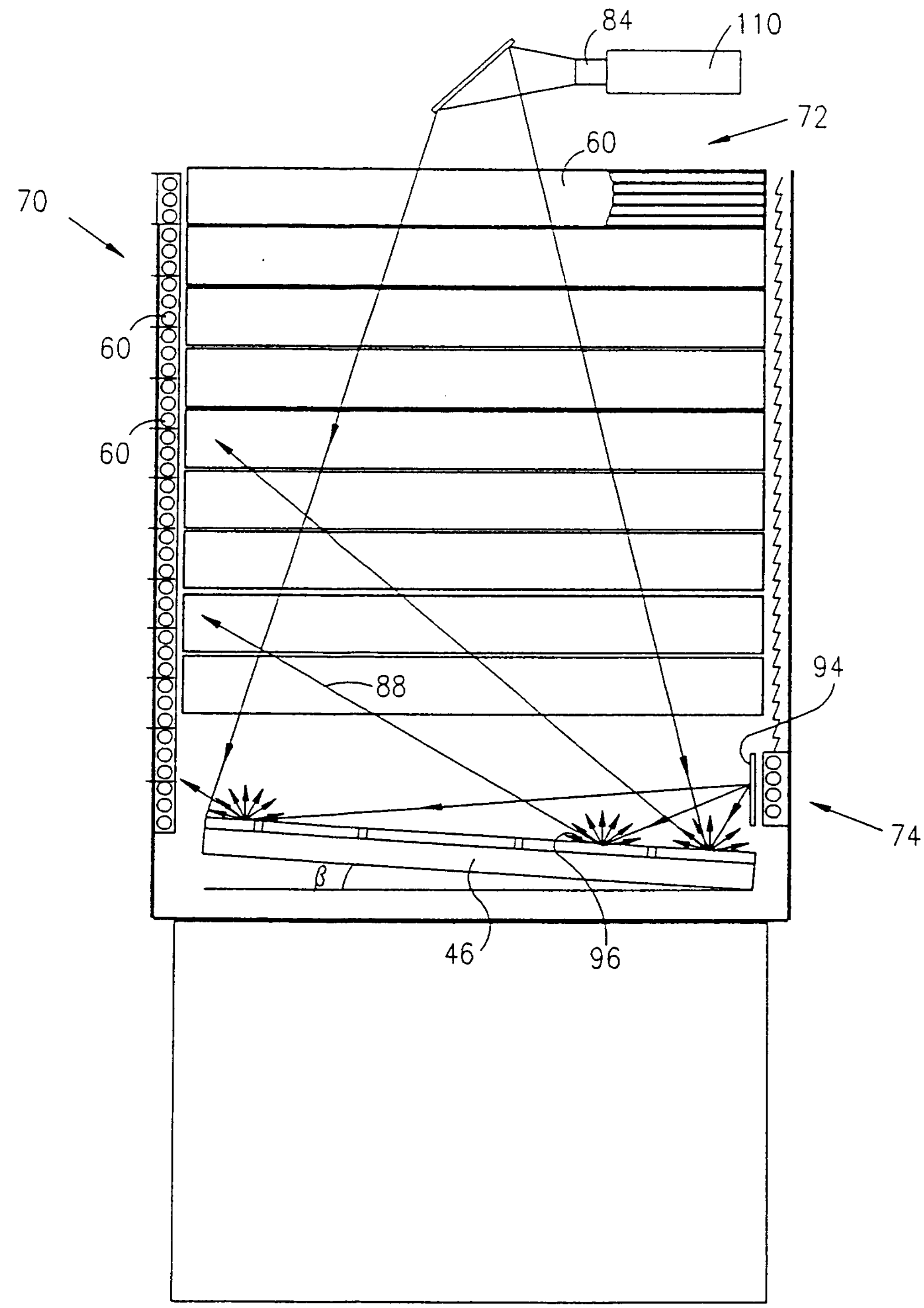


FIG. 9

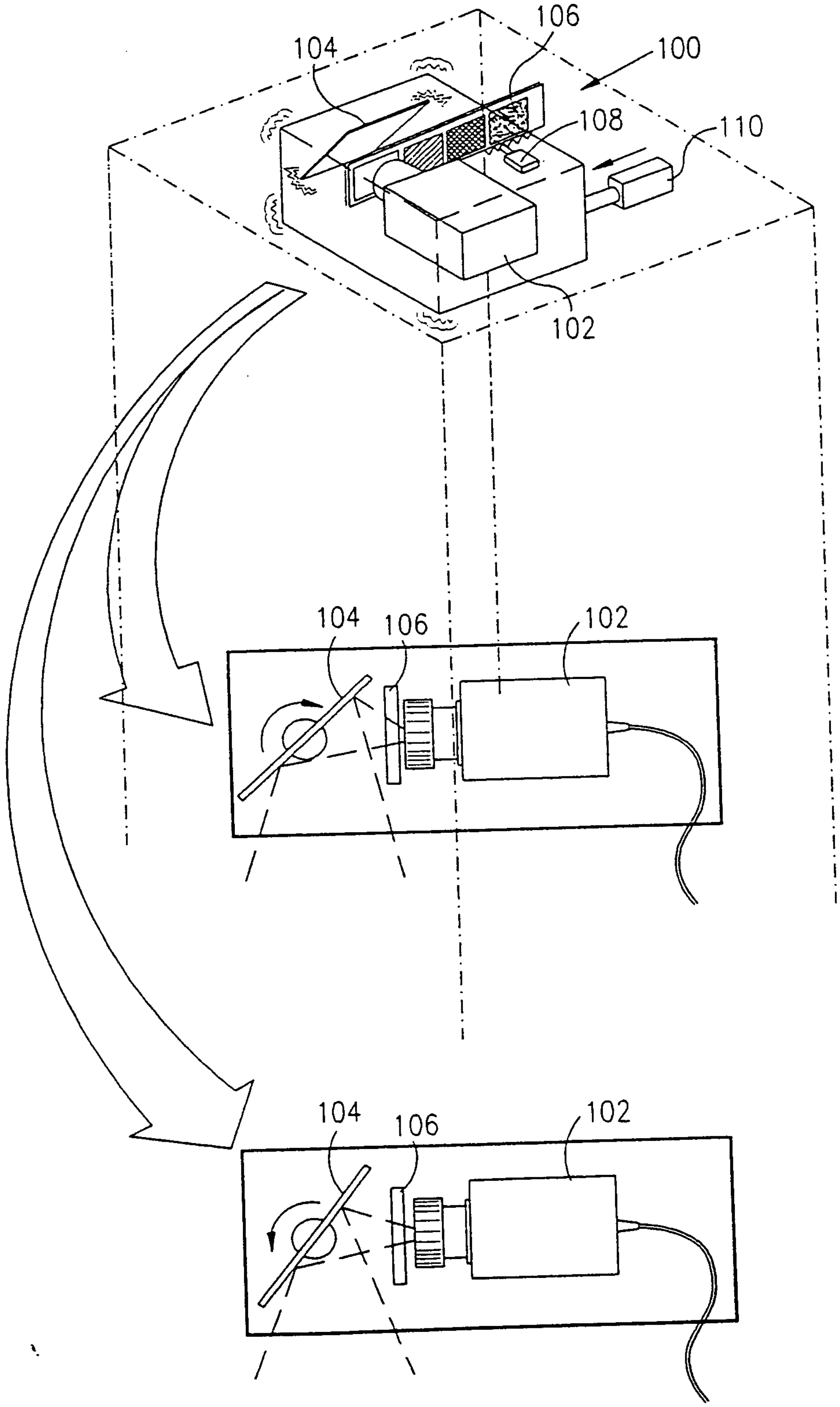


FIG. 10

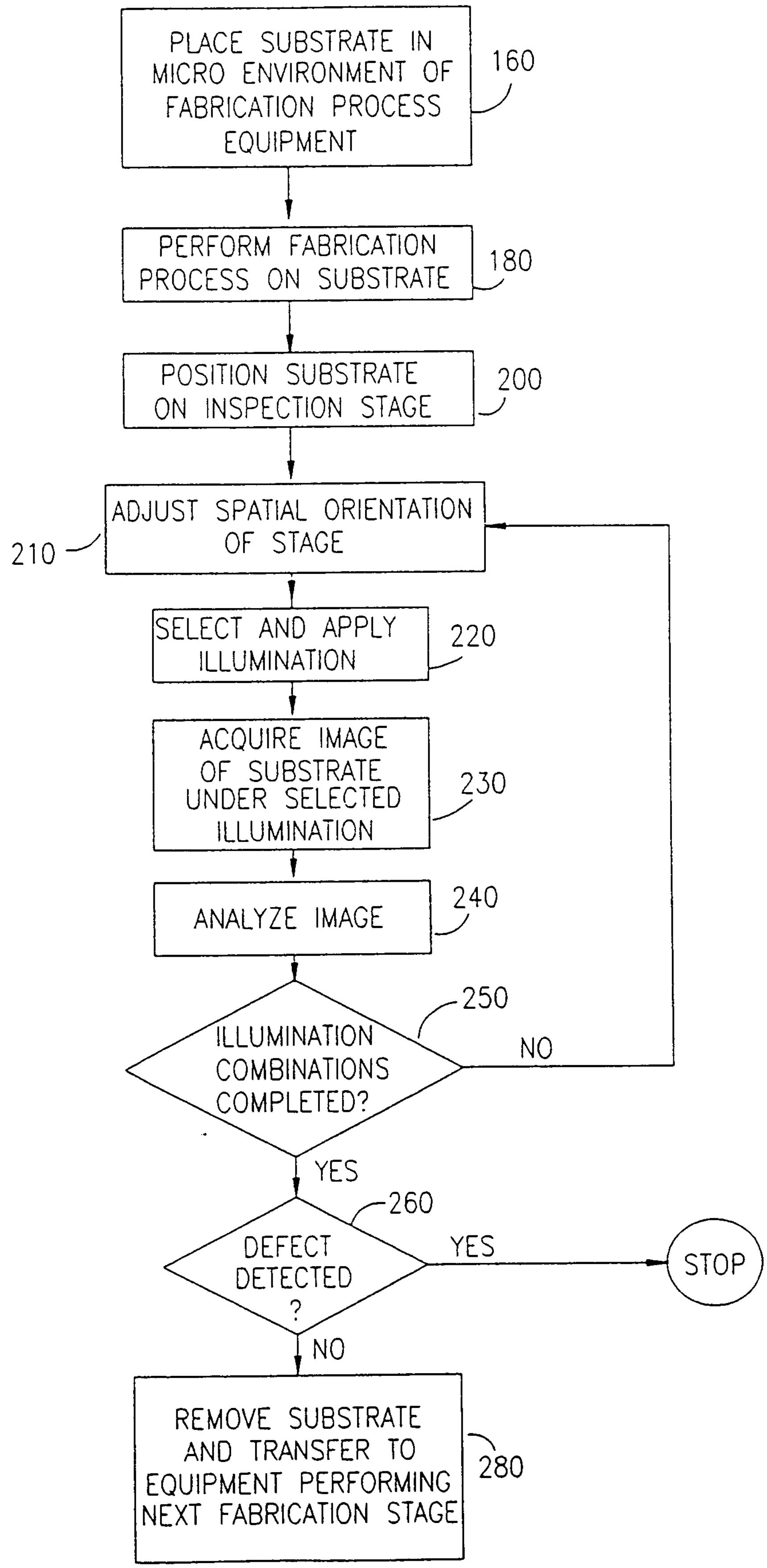
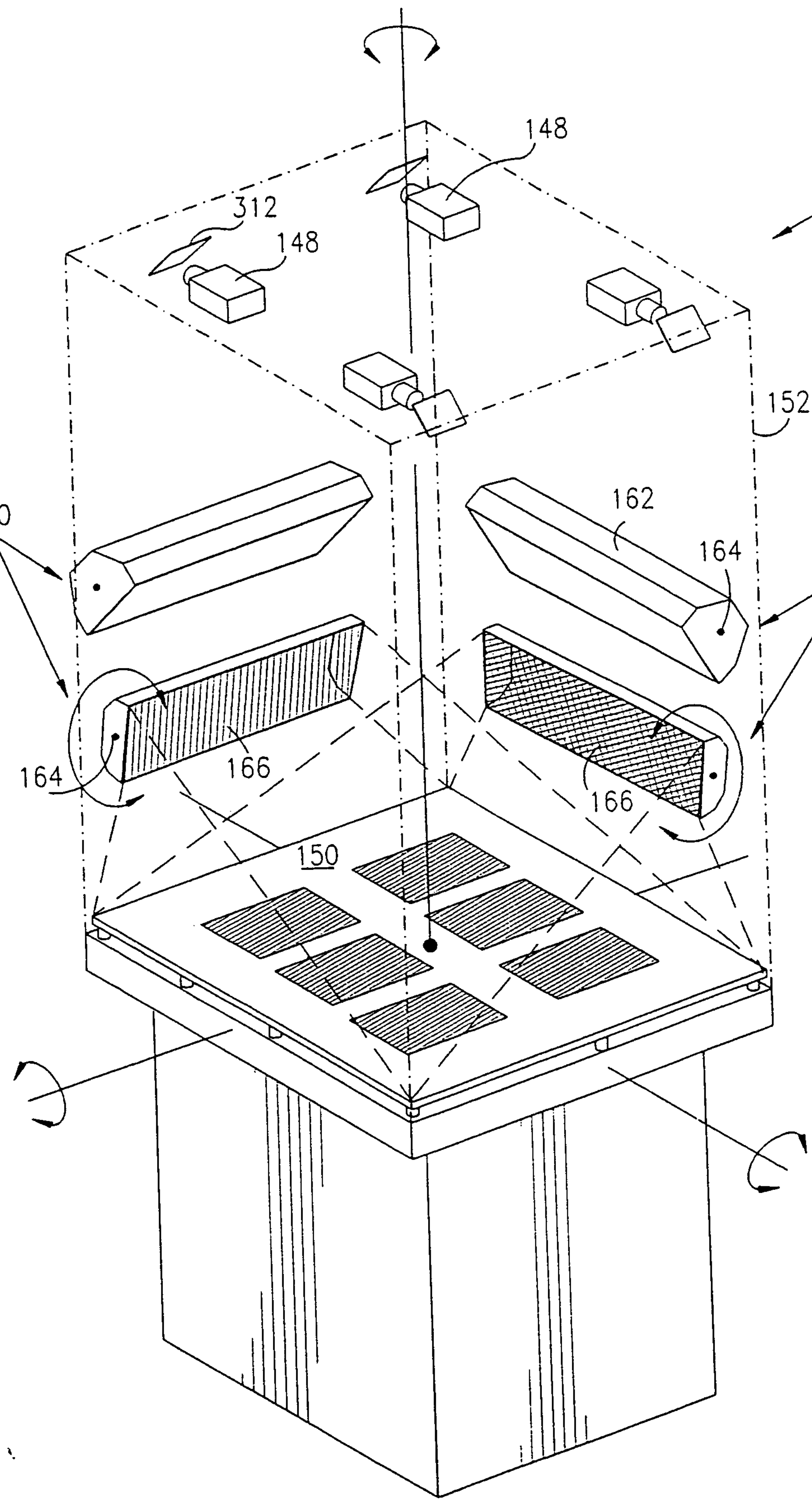

PLACE SUBSTRATE IN MICRO ENVIRONMENT OF FABRICATION PROCESS EQUIPMENT
160
PERFORM FABRICATION PROCESS ON SUBSTRATE
180
POSITION SUBSTRATE ON INSPECTION STAGE
200
ADJUST SPATIAL ORIENTATION OF STAGE
210
SELECT AND APPLY ILLUMINATION
220
ACQUIRE IMAGE OF SUBSTRATE UNDER SELECTED ILLUMINATION
230
ANALYZE IMAGE
240
ILLUMINATION COMBINATIONS COMPLETED?
250
NO
YES
DEFECT DETECTED ?
260
YES
STOP
NO
REMOVE SUBSTRATE AND TRANSFER TO EQUIPMENT PERFORMING NEXT FABRICATION STAGE
280

FIG. 11



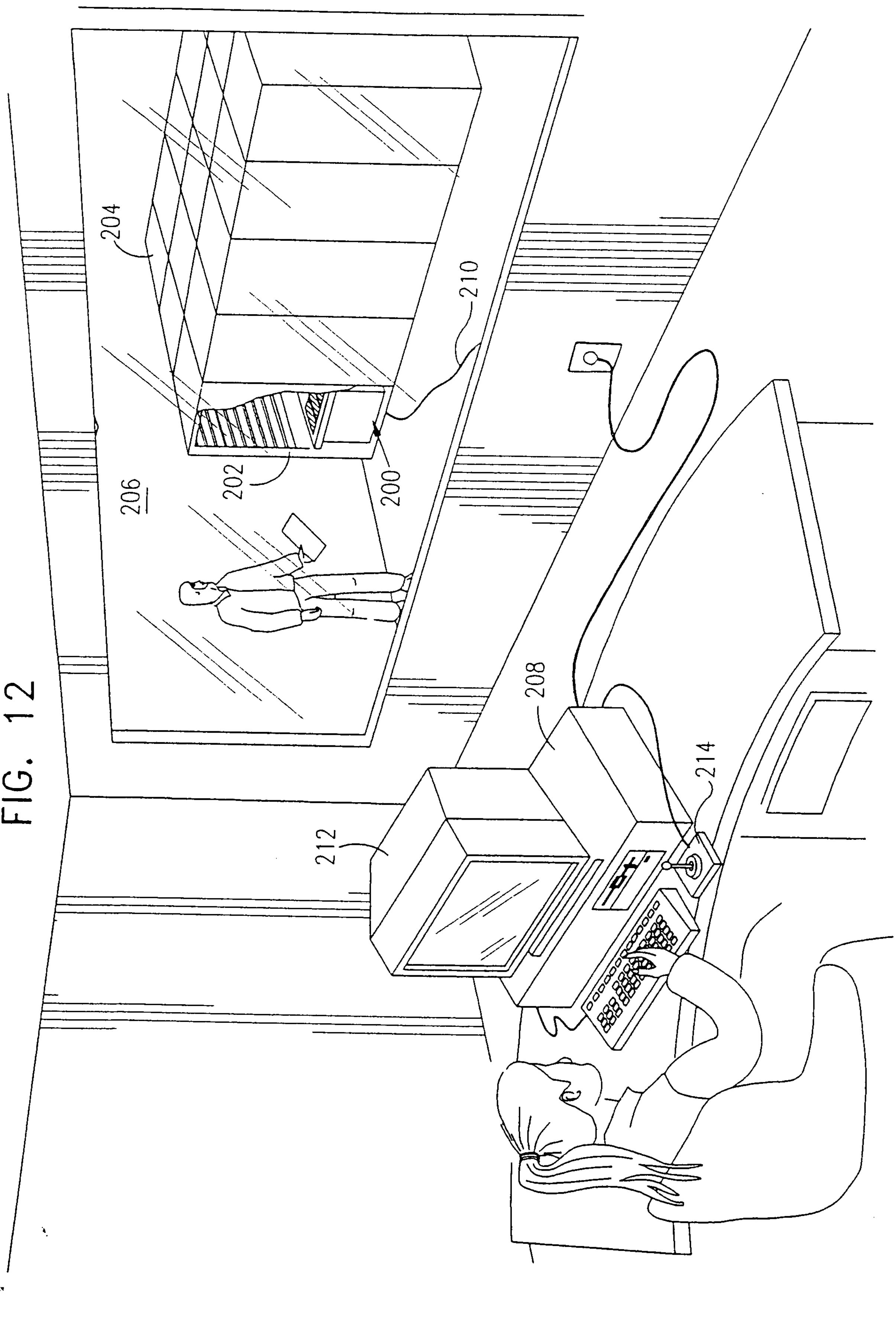


FIG. 12